Public Acceptance of Geological Disposal of Carbon Dioxide and Radioactive Waste: Similarities and Differences

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Abstract Public acceptance of geological disposal of carbon dioxide (CO_2) and that of radioactive waste (RW) are fundamentally different problems because of the history, scale and nature of the two issues. CO_2 capture and storage (CCS) is a technology in its infancy with no full-scale commercial application and there are only a handful of full-scale storage projects globally. CO_2 storage is almost completely unknown whereas RW disposal has been the subject of highly charged (often unresolved) political debates for decades and all matters nuclear are viewed as both the subject of fear and fascination in the broader cultural and political context. Nevertheless, there are some notable similarities, including: the difficulty of extricating not-in-my-backyard (NIMBY) considerations from other concerns; the inability to divorce the politics of waste streams from the underlying electricity generating technologies; the challenge of communicating the highly technical nature of both issues; and the role that both CO_2 storage and RW play in the larger debate over energy policy, particularly as a proxy issue for non-governmental organizations. A key question identified is whether CCS will continue to be portrayed as the saviour of fossil fuels or whether it becomes an Achilles' heel, much as resolving RW has become a necessary condition for further expansion of nuclear power. It is too early to draw any firm conclusions regarding the acceptability of CO_2 storage because of the current low levels of awareness. Nevertheless, the nature of the CO_2 storage problem tends to support the view that it will be less controversial than RW because of the large number of storage sites needed, public familiarity with CO_2 and the need to resolve storage at the very beginning before CCS can proceed on large point source facilities.

Keywords Public attitudes • Social acceptance • Geological disposal • CO_2 storage • NIMBY

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F.L. Toth (ed.), *Geological Disposal of Carbon Dioxide and Radioactive Waste: A Comparative Assessment*, Advances in Global Change Research 44,
DOI 10.1007/978-90-481-8712-6_10,

1 Introduction

The differences between the geological disposal of carbon dioxide (CO_2) and radioactive waste (RW) would seem, on its face, to be enormous, both technically and with respect to the attitudes of both local communities and the wider public. It is a reflection of difference in public acceptability, or at least the image that proponents wish to generate, that supporters of CO_2 capture and storage (CCS) assiduously avoid use of the term ‘disposal’, in spite of the fact that, in its most straightforward sense, there is no interest in ever retrieving the ‘stored’ CO_2. In the case of RW, however, ‘storage’ is used to describe an interim measure, often above ground, where the wastes are subject to human oversight and monitoring. ‘Disposal’ of RWs refers primarily to the waste being placed in a deep geological repository, where the need for monitoring is expected to last for perhaps 100–300 years, and where the ultimate goal is for a passive facility where the waste will be permanently sealed. By contrast, the term ‘disposal’ is rarely used in the case of CO_2 (Palmgren et al. (2004) being a notable exception). Instead, in virtually all cases, ‘storage’ of CO_2 refers to a similar situation to ‘disposal’ of RWs, whereby the CO_2 is stored in a deep geological reservoir and monitored for an extended period during the injection and post-injection phases.

The nature of the interaction with the geological formation is also very different. Unlike RW management, which uses a multi-barrier approach to waste containment, the large volume of CO_2 pumped underground means that from the outset the CO_2 will be contained only by the geological reservoir itself. By comparison, regulatory and scientific analysis of CO_2 storage is in its relative infancy and the duration of monitoring needed and the responsibility for monitoring post-closure are the subjects of active ongoing debate.

The scale differences and levels of experience are striking. A 1,000 MW light water reactor will generate some 800 t of low- and intermediate-level waste and 30 t of spent nuclear fuel per year IAEA (1997). Although debates over final storage are ongoing in many countries, in the meantime wastes have been managed worldwide for five decades. By contrast, a new coal-fired plant of similar size will produce perhaps 6 million tonnes of CO_2 (Mt CO_2) per year. To date, the largest CO_2 injection sites of roughly 1 million tonnes per year each are Sleipner off the coast of Norway (1996), Weyburn in Canada (2000) and In Salah in Algeria (2005). Total monitored CO_2 storage worldwide is thus still less than would be needed for a single power plant.

If CCS were to become a major climate mitigation option, the scale of CO_2 storage activities would be comparable to the current operations of the oil and gas industry. One gigatonne (Gt) of carbon (Gt C) (~3.6 Gt CO_2) is equivalent to capture from 600 1-GW plants and would require the equivalent of 3,600 injection projects at the scale of Statoil’s Sleipner project (MIT 2007). The storage sites would require injection of roughly 60 million barrels of supercritical CO_2 each day, or two thirds the current global petroleum production volume (Friedmann 2006). Nuclear power, by contrast, is already operating on a scale of two thirds of a Gt C; as of April 2008, there were 372 GW of nuclear power in operation (IAEA 2008).

Albeit difficult to compare easily, CO_2 is non-toxic at lower concentrations, although at high concentrations it acts as a simple asphyxiant. Air normally contains 0.03% CO_2; at concentrations of 2.5–5% headaches and upper respiratory problems may result, at 10% unconsciousness within 1 min and at 20% respiratory arrest. The threshold limit value is set at 0.5% or 5,000 ppm (Kent 1998). By contrast, even stipulating the existence of any threshold effects for RWs has proven extremely controversial and on a precautionary basis it has become conventional to extrapolate linearly from known high radiation dose effects down to lower doses with no assumed safe dose threshold. Assumptions are required because statistically reliable robust data is very difficult or impossible to obtain for low radiation exposures. For a critique and review of the no-threshold-linear-dose–response assumption, see Prasad et al. (2004).

The political and public context is also vastly different. High-level RW disposal, in particular, has been the subject of intense debate, usually at the national level and has often continued unresolved for decades; for example, the US National Academy of Sciences first proposed deep geological disposal of spent nuclear fuel in 1957 (NAS 1957). By contrast, CO_2 storage is a recent subject that is still largely unknown to the vast majority of the public (EC 2007; Reiner et al. 2006). CCS is playing an increasingly important role in the larger debate over climate change, the future of coal and decentralized generation, but that awareness is largely restricted to policy elites rather than to the general public.

RW is an inescapable problem, in the sense that even if no additional nuclear power plants are built, there will still be a need to deal with the legacy waste that has accumulated. By contrast, concerns over CO_2 are currently only hypothetical, based on the expectation of first large-scale demonstration, then commercialization and widespread expansion of CCS technologies over the next few decades. The converse is that, given the volumes from even a single plant, it will be essential to resolve the storage question upfront for CO_2 whereas RW, in the absence of agreed long-term solutions, can be, and has been, dealt with on a temporary or ad hoc basis for many years. The physical characteristics of CO_2 would seem to lead to far more local (and far more frequent) debates over siting than the national debates over RW siting that usually focus on very few (often only one) site. Nevertheless, we will also explore the similarities in terms of the way in which controversies over storage impact on the wider debates over energy and climate policy, the engagement and attitudes of non-governmental organizations (NGOs), and the basis for local opposition or support.

We divide our analysis into four parts: (1) a brief review of the history of each subject and a discussion of the role that both CO_2 storage and nuclear waste play in the larger debate over energy policy, particularly as a proxy issue for NGOs; (2) general public opinion on the subjects; (3) the role of NIMBY (Not In My Back Yard) and compensation to local communities in facilitating the siting of storage facilities; and finally (4) the extent to which culture, fear and iconography influence public perceptions and political debate (on which, see also de Groot and Steg 2011).

2 History, Energy Choices and the Views of NGOs

2.1 Radioactive Waste

During the phase of rapid nuclear development of the 1950s and 1960s, the speed with which the first nuclear power plants were designed and sited was breathtaking in the context of the infrastructure siting and energy policy debates of the past 30 years. Consider the case of, arguably, the world's first commercial nuclear power station at Calder Hall: that four-reactor station went from concept to power generation in only 42 months (Jay 1956, cited in NDA 2007).

These developments in the years after the Second World War (WWII) led RW to become a new problematic topic for science and technology public policy. Of course, awareness of radiation as a cause of biological harm was already known scientifically before WWII, but that itself had not been sufficient to generate widespread fears. In fact the genesis of societal fear of radiation and nuclear technologies is a complex and fascinating story explored extensively by Weart (1988), whose thesis is that nuclear science and technology manifested numerous sources of fear that had long existed in society: nuclear power just happens to be intrinsically scary.

Over time, nuclear power became increasingly politically controversial, especially following the 1979 accident at Three Mile Island, Pennsylvania, USA, and the disaster in 1986 at Chernobyl in Ukraine. However, even before these events the seeds of later policy difficulties had already been sown. For instance, in the UK in 1976 the report of the Royal Commission on Environmental Pollution (RCEP), known informally as the 'Flowers Report', famously proposed that no commitment should be made to a 'large programme' of nuclear power until a 'method exists to ensure the safe containment' of RWs 'for the indefinite future' (RCEP 1976, p. 202). The Flowers Report provided those with a firm resolve to oppose all nuclear energy developments with the opportunity to block future nuclear power developments merely by rendering the RW question unanswerable. Similar seeds of such difficulties linking resolution of the waste disposal question to nuclear power development were also being sown in Germany and elsewhere (Darst and Dawson 2008). Indeed, the pre-eminence of disposal (in Germany and elsewhere) is inextricably linked to the decisions over reprocessing. Until 1994, German utilities were obliged to reprocess spent fuel to recover the usable portion and recycle it. From 1994 to 1998 reprocessing and direct disposal were equally acceptable to the federal government, but the policy of the coalition government from 1998 is for direct geological disposal of spent fuel and no reprocessing after mid-2005 (WNA 2008).

In this way RW became the Achilles' heel of nuclear power. In such a paradigm RW takes on an importance far beyond the narrow issues of waste and the associated hazards. Arguably waste becomes a proxy battle for much wider questions about nuclear energy, the nature of electricity systems and associated infrastructures and, in extremis, the very nature of industrial and post-industrial society.

2.2 Carbon Capture and Storage

CCS is often put forward as the saviour of fossil-fired generation, and especially in preserving coal as an element in the fuel mix of a carbon constrained world. One might consider, therefore, a situation where CCS might take on the status of Achilles' heel for the fossil fuel industry. To some extent the recent insistence that no new coal plants be built without CCS requires the same resolution. Reflecting the large scale of the problem, the main barrier to penetration of CCS is, however, costs, and, in particular, the costs of capture (IPCC 2005). Resolving the ongoing debate over long-term liability is viewed by many investment firms as essential to the financing of CCS (de Figueiredo 2007). Experience from the RW debate might imply that success for some might be achieved by merely preventing any resolution of questions concerning CCS deployment.

The political debates over both RW and CCS have been shaped by many leading environmental NGOs, almost all of which are strongly anti-nuclear. Nuclear issues catalyzed many of the major environmental groups that were founded in the late 1960s and early 1970s. Greenpeace's original concern was opposition to French nuclear weapons tests in the Pacific, and Friends of the Earth was founded by David Brower, in part out of frustration at the unwillingness of the Sierra Club to oppose nuclear power in general and the Diablo Canyon nuclear plant in California in particular (Shabecoff 1993). Opposition to nuclear power was also central to the creation of many Green Parties (Richardson and Rootes 1995).

This anti-nuclear disposition on the part of most NGOs has remained steadfast in the face of growing concerns over climate change. Indeed, opposition to nuclear power in part explains the willingness of NGOs to remain neutral or even to be slightly favourably disposed towards CCS. Some, such as the Natural Resources Defence Council and Environmental Defence, adopt a pro-CCS position in the hopes of pushing a more aggressive CO_2 concentration target and bringing countries such as China into an emissions control regime (Wong-Parodi et al. 2008). In the US, support among NGOs is also combined with the drive for greater use of coal gasification technology, which would also reduce emissions of traditional air pollutants. By contrast, other NGOs, such as World Wide Fund for Nature (WWF), express support for CCS as a 'necessary evil', in the hopes that the success of CCS will signal the demise of any efforts to revive nuclear power. Stefan Singer, its European Policy Office director, has described WWF's support for CCS as contingent on a move away from nuclear (Singer 2007).

Other NGOs, such as Greenpeace, are concerned at the possibility of increased focus on CCS diverting public resources away from renewables and increasing support for the fossil fuel economy (Rochon 2008). In a survey of over 500 European stakeholders, NGO respondents were also far more likely to take many of the associated risks of deployment quite seriously and, in particular, to worry about the potential for investment in CCS to divert resources away from favoured technologies such as renewables (Shackley et al. 2007).

CCS, although largely unfamiliar to the vast majority of the public, has come to play an increasingly central role in the debates over energy policy and climate change policy in many countries. Perhaps the country where the greatest attention has been paid to CCS is Norway, where a coalition government fell in 2000 over proposals to include CCS in Norway's first ever natural gas-fired power plant (Quiviger 2001). In its so-called 'Soria Moria Declaration' of October 2005, the three coalition parties agreed that all new licenses for gas-fired power plants require CCS. The Bellona Foundation, a major Norwegian NGO, has taken a lead in promoting CCS as an environmentally friendly energy source not just in Norway, but in Europe and beyond. Nevertheless, cost considerations forced the plant at Mongstad to scale back to capture 100,000 t CO_2 in its first years of operation rather than full-scale capture (which would be roughly 1.3 Mt CO_2) and the project has decided to simply release the CO_2 to the atmosphere (Berglund 2007).

Other countries where CCS has played an increasingly important role in national energy and climate policy include Australia, the Netherlands, the USA, the UK and Germany. In all cases, the debate over CCS is tied in closely to ongoing debates over energy security and intra-fuel competition. In Europe, concerns over increased reliance on Russia for natural gas has increased the appeal of domestic coal as well as imports from countries considered more stable (Williams 2008). In the USA and Australia, the two largest coal producers in the developed world, CCS is intimately tied to the continuation of coal-fired electricity generation.

Opposition to continued use of unabated coal-fired generation has increased dramatically in the past few years. In the USA, Texas Utilities was sold in 2007, in large part because of opposition to unabated coal plants; Germany has recently seen proposals for large new coal plants defeated in local referenda (Deggerich 2008), and plans for a 1.6 GW coal-fired plant at Kingsnorth in the UK has come under fire from the Royal Society as well as from over 200 Members of Parliament and activists in the Camp for Climate Action (Adam and Macalister 2008).

2.3 Similarities and Differences

One important distinction between RW and CO_2 is that RW is not a single well-characterized entity. Even before WWII, industrial activities involving radioactive materials had already generated significant volumes of materials equivalent to RW. Examples of harmful materials that pre-date capture by RW policy include materials associated with: pre-war radium therapies, luminous paints used in WWII aircraft and pre-war clocks, uranium used in the glassware and lamp mantle industries. To this day such materials (i.e. those created before 1946) are still not officially regarded as RWs in the UK, despite the equivalence of content and hazard that they have with later official wastes (Nuttall 2005). Historical context and administrative classification can be important in defining RWs in addition to the various science-based issues and hazard-related considerations that necessarily affect such processes.

There are numerous classifications of RW and numerous conditions in which it can be found. The main UK classifications of waste are therefore high-level waste (HLW), intermediate-level waste (ILW) and low-level waste (LLW). LLW is relatively unproblematic, as evidenced by the many countries with LLW disposal facilities. Of these British formal classifications of RW, HLW and ILW are defined so as to suit the output streams of aqueous nuclear fuel reprocessing.

Regardless of the fuel cycle, the dominant paradigm is geological disposal. This is near universally agreed as being either current policy, or an eventual policy goal. The slow pace of progress towards these goals has, however, in many cases motivated significant work into surface and near-surface managed storage options, albeit usually framed as an interim measure. Such measures have, however, lasted for decades in many countries.

Interestingly, the UK Committee on Radioactive Waste Management (CoRWM) endorsed the concept of geological disposal in 2006 and rejected formal moves towards monitored ‘retrievability’. As such, the committee aligned itself with orthodox scientific approaches to the problem and away from moves that had started to take root that were trading small amounts of notional safety off against popular preferences of inexpert groups of the public (CoRWM 2006). By contrast, in France, it is only when waste cannot be reused or recycled under current technical and economic conditions that it may be disposed of (Warin 2007).

The paradigm of deep geological disposal bears superficial similarity to issues of CO_2 storage and hence it is this approach that we shall focus on in this chapter.

Threats to an RW repository fall into two classes. Those which are more amenable to scientific analysis relate to natural geological and hydrological processes, together with the materials science of immediate waste encapsulation. These natural processes can be analysed for the potential for harmful radionuclides to be released and for the pathways by which they might be transported so as to bring them into contact with the biosphere and human populations. Timescales of such risks are typically measured in tens or hundreds of thousands of years or more. The second class of threat is more difficult to analyse and involves human intrusion into a geological repository either accidentally or deliberately. Key to appreciating these latter risks is the need to reflect upon the timescales involved. Even at 10,000 years old an RW repository would still be young compared to its design life. Human society, however, if it still exists, could by then have gone through two or more cataclysmic collapses and rebuildings. There are few artefacts left from the Mesolithic era 10,000 years ago, when humans first cultivated grains and domesticated animals. Who knows what the future will hold, but it is not unimaginable that millennia from now citizens of a semi-industrialized world might intrude on an RW repository by boring a deep well or that they might seek to excavate, in a primitive fashion, a long sealed repository poorly understanding its contents. In other imaginable futures, spent nuclear fuel might be viewed as a resource that could be extracted and used. The timescales and the risks of deliberate and accidental intrusion into sequestered RW or CO_2 differ from one another, and in each case are difficult to assess or quantify.

Arguably all considerations of environmental sustainability can usefully be expressed in terms of the interests and needs of our great-grandchildren 100 years from now. Commentators (including eminent economists) have pointed out that conventional economic tools of discounting undervalue the needs and interests of future generations (Weitzman 1998). By implication, much smaller, or perhaps even negative, discount rates should be considered. By contrast, most public surveys have supported the view of Charles Galton Darwin that ‘most human beings do not care in the least about the distant future. Most care about the conditions that will affect their children and grandchildren, but beyond that the situation seems too unreal, and… uncertainties are too great’ (Darwin 1952).

Even more so than for RW, storage of CO_2 underground is *nominally* a matter involving lifetimes of thousands of years, but is primarily a question of the next century, during which the adequacy of the global response to climate change will be revealed (Herzog et al. 2003). Aside from localized effects, such as migration to someone’s basement, leakage is of concern because it will add to the atmospheric burden of CO_2 and thereby reduce the effectiveness of CCS. Some have argued that the only acceptable leakage rate when viewed from the perspective of public explanation is zero (Ha-Duong and Loisel 2009), but there have been no studies on how the issue will be framed and what counterfactuals will be assumed. The British Geological Survey, for example, has argued that currently ‘leakage’ from fossil generation is effectively 100%, so even accounting for the energy penalty and the occasional leak, CCS is a far more climate friendly option (HCSTC 2006).

3 Demographics and Opinion

3.1 Radioactive Waste

Data from Eurobarometer surveys reveals quite stable patterns in public attitudes to RW (EC 2005, 2008a). The dominant opinion of Europeans polled is that roughly three quarters consider themselves to be ‘not well informed’ on these matters. Generally, northern Europeans report higher levels of understanding than those in southern Europe. Of respondents reporting that they are inclined to support nuclear energy, 65% claim to be well informed about RW, whereas for those averse to nuclear energy 79% report being poorly informed on RW. Even though a large majority (71%) of Eurobarometer respondents correctly understood that there are several types of RW but, tellingly, 78% incorrectly believed that all types of RW are very dangerous, which is roughly the same level as surveys conducted in 2001 (EC 2002) and 2005 (EC 2005).

Although almost all Europeans (93%) believe that there is an urgent need to finding a solution to RW now, rather than leaving it unsolved for later generations, over 70% do not believe there is any safe way of getting rid of HLW (EC 2008a). Deep underground disposal is seen as the single most appropriate solution for managing high-level RW over the long term, but support is only moderate (43% vs. 36% opposed). Although the overall view of nuclear power improved between 2005 and 2008, there was relatively little change in the views towards waste disposal. In spite of decades-long public debate over nuclear power, the public remains divided when asked whether nuclear power was a major contributor to global warming (EC 2003; Reiner et al. 2006).

Information does not necessarily bring support. The 2008 survey found that those who felt well informed were *more* likely to agree with the statement: 'There is no safe way of getting rid of highly radioactive waste' (EC 2008a). There is also keen interest for affected individuals to be directly involved in decisions. Few amongst the public (15%) would defer to the authorities in the siting of an underground storage facility or would even want local NGOs to be consulted on their behalf (22%); instead, the majority (56%) wanted to participate directly in the process.

It is sometimes assumed that knowledge, interest and enthusiasm in nuclear matters are correlated, but it is important to stress that there are many people firmly opposed to nuclear energy who are expert in its intricacies, which further calls into question the 'deficit model' view of science which argues that support is linked to knowledge and that opposition can be overcome via education (Sturgis and Allum 2004). Such anecdotal observations prompt us to question whether the observed correlations are causal. Women are more nervous about nuclear power and RW and also know less about it, but is the hostility to all matters nuclear related to the lack of knowledge and if so, how? Furthermore, do they know less about nuclear issues because they are less likely to have studied physics and maths in school? Is the 'gender' aspect of public attitudes to RW merely a reflection of more fundamental sociological or perhaps sociobiological issues relating to teenage girls and boys and their interests in school or with regard to the technologies in question? These issues will be addressed immediately below and in the next section.

Public attitudes to RW differ according to the sex of the respondent reporting. Women tend to hold much more negative opinions—46% of men favoured nuclear power compared to 29% of women in the 2005 Eurobarometer poll. A 2008 ABC News/Stanford University poll in the USA found that 60% of men supported expansion of nuclear power versus only 29% of women (Langer 2008). Women are also less likely to favour deep underground storage (37% vs. 49% for men) and less likely to believe that nuclear power allows for diversification of the energy supply (57% vs. 72% for men). Aside from such negative views, women are generally less well informed about the issues—in the 2005 Eurobarometer report, men outperformed women on a range of knowledge questions.

While it is true that women are less likely to have training in the sciences and are more sceptical of technology, Barke et al. (1997) found that even female physical scientists judged the risks from nuclear technologies to be higher than their male counterparts. Flynn et al. (1994) found that white males, in particular some 30% of white males, judged risks to be lower for every hazard described. Slovic (1999) described this subgroup as 'characterized by trust in institutions and authorities and by anti-egalitarian attitudes'. In particular, the subgroup were far less likely to agree that local residents should be able to close a nuclear power plant if they feel it is not run properly and that the public should vote on issues such as nuclear power, but were far more likely to trust the experts who build, operate and regulate nuclear power stations and to believe that government and industry can be trusted to make the right decision when managing technological risks.

3.2 Carbon Capture and Storage

By contrast, at a basic level, the lay public has a quite good familiarity with CO_2. Studies of US, British, Japanese and Swedish publics find a clear understanding that automobiles, coal-fired power plants and steel mills produce CO_2 and that trees absorb CO_2 (Reiner et al. 2006). CO_2 storage is less familiar than RW storage and studies in various countries find that there is very little awareness of CCS or even clear recognition that CCS addresses climate change as opposed to other air pollutants or even other environmental problems such as toxic waste or water pollution (Reiner et al. 2006). Similar results have been found in opinion surveys in Spain and in Australia.

The major concern voiced in focus groups (Shackley et al. 2005) was concern over leakage of CO_2 into the atmosphere followed by ecosystem and human health effects. Surveys of stakeholder groups (government, industry, academia and NGOs) have found that both CO_2 storage and CCS generally are considered to be relatively low risk (Shackley et al. 2007). Nevertheless, NGOs tend to view both CCS and storage in particular as somewhat riskier than other stakeholders. The major concern expressed is not over the risks of deployment of CCS per se, but over the additional fossil fuel use necessary because of the energy penalty in the capture process. Other concerns include human health and safety from onshore CO_2 storage and environmental damage from both onshore and offshore CO_2 storage.

Unlike in the case of nuclear power and RW, most studies have not found any appreciable gender gap. The Australian study by Miller et al. (2007) is the most prominent to find that women were more sceptical than men about CCS (as opposed to CO_2 storage specifically), but the survey was non-representative and fully 79% of respondents were female, making any extrapolation of their findings, even to the Australian population, questionable.

Whether more information increases acceptance of CCS is also difficult to study because of the novelty of the issue. Itaoka et al. (2009) have extended their studies of information effects and find that although greater knowledge is associated with stronger support, after information is provided support drops, which the authors explain as being related to lack of awareness of the risks. More generally, Dutch social psychologists working in this area have conducted a number of studies on the stability of individual preferences when faced with information on a novel and complicated technology (see, for example, de Best-Waldhober et al. 2009). They find that many respondents provide 'pseudo-opinions', or 'non-attitudes', whereby respondents are willing to provide an opinion even on topics they know nothing about. These pseudo-opinions are found to be unstable and easily changed according to the specific information provided. This instability of public opinion should provide a caution when drawing conclusions from any study of attitudes towards CCS no matter how carefully designed. Finally, even more problematic is that the current status of risk communications on CCS has been judged to fall far short of best practice and in many cases is extremely weak, so that what information that is out there for the interested layperson is actually not up to the task of providing a clear exposition of the basic facts (Reiner 2008).

4 Location, NIMBY and Compensation

Siting RW facilities has proven exceedingly difficult around the world. As Gerrard (1996) notes in the context of the USA, 'Despite scores of siting attempts and the expenditure of several billion dollars since the mid-1970s… there is only one small radioactive waste disposal facility; only one hazardous waste landfill… and a small handful of hazardous waste treatment and incineration facilities' (Gerrard 1996).

The Facility Siting Credo (Kunreuther et al. 1993) offers a series of suggestions on how to successfully site a major infrastructure project: (1) instituting a broad-based participatory process; (2) seeking acceptable sites through either a volunteer or a competitive siting process; (3) keeping multiple options open at all times; (4) guaranteeing stringent safety standards; (5) ensuring geographic equity; and (6) making the host community better off. Most national-level processes aimed at choosing an RW site have been unwilling or unable to comply with many of these recommendations (e.g. competitive siting, geographic equity, keeping many options open). Although there are few existing examples of siting CO_2 storage facilities near a concerned community, the scale of CO_2 storage means that there will inevitably be many sites at a national level, which means that it will be easier to meet some of the elements of the credo than would be the case for a single national RW repository.

One area that has drawn considerable attention is the possibility of making the host community better off. Compensation combined with other incentives has been used successfully to gain public acceptance of locally contested infrastructure projects in settings as diverse as Japan, France, Australia and the USA (Lesbirel and Shaw 2005). For example, in France public utilities offer reduced electricity prices to host communities and in Japan compensation is provided to both the host community and surrounding communities. By contrast, other studies have found that compensation may prove counterproductive (Frey et al. 1996). Singleton's study (Singleton 2007) of the potential for compensation in the case of CCS is largely sceptical of the potential role that might be played.

If the problem is purely one of NIMBY, then one would expect that compensating for losses in property values or other negative impacts should be relatively simple. If, however, the issue is fear of a technology or waste product or distrust in those, then straightforward compensation will be made more difficult or perhaps impossible.

NIMBY or NUMBY (Not Under My Backyard) as coined by Huijts (2003) poses a serious challenge to the siting of CO_2 storage. Jaeger (2007) argues that the necessary public trust can be gained: 'If the businesses involved in CCS would accept collective liability for the safety of CCS, they could establish the kind of credibility the nuclear industry is lacking.' Huijts et al. (2007) offer one of the few case studies of the attitudes of local residents ($n = 103$) in the vicinity of a potential storage site for CO_2. They found that public attitudes towards CCS in general were slightly positive, but attitudes towards storage nearby were slightly negative. In spite of having little knowledge about CO_2 storage, the lay public showed little desire to learn more. Therefore it is not surprising that trust in those providing information was seen as particularly important. NGOs were found to be trusted most, and industry least, by the general public. Trust in different actors appeared to depend on perceived competence and intentions. Moreover, previous experience with the organizations or actors involved, concerns over accountability, and openness can also play important roles in shaping trust (see generally, Cvetkovich and Löfstedt 1999).

Wong-Parodi et al. (2007) conducted focus groups in two communities in California's Central Valley and found that compensation is critical for technology acceptance and that community involvement was essential for the success of the project, but that past experience was critical for defining a community's willingness to believe they would receive compensation. Rio Vista's experience with royalties from natural gas and mineral rights which accrued to the long-time landowners left them more favourably disposed to siting of CCS facilities whereas in Thornton, experience with water treatment left residents distrustful of further projects.

In a survey of 1,001 Nevada residents, Kunreuther et al. (1990) found that perceived risk (e.g. risk to future generations) depends in part on the trust placed in the US Department of Energy to manage the repository safely. Opposition did not decrease significantly if compensation of US$1,000–5,000 in rebates per year for 20 years was offered to residents. Rather, the public needs to be convinced before compensation is considered that the repository will possess minimal risks to themselves as well as to future generations, and that the site currently targeted is suitable.

Of course, success is not simply a function of compensation. In the cases where a high-level RW facility has been successfully sited, such as in Sweden and Finland, a key element in the success has been public engagement (Litmanen 1999). One of the more successful examples of consensus building was the CoRWM process in the UK, which differed from all previous (unsuccessful) approaches to policy for the management of RW in that from the outset it was not constructed to be simply a scientific and technical problem. CoRWM recognized from the outset that it was as much a sociological and political problem. In addition to issues considered by previous policymaking bodies, CoRWM devoted much energy to what the committee termed 'ethics', and in particular 'intra-' and 'intergenerational' ethics (CoRWM 2006). CoRWM suggests that intergenerational equity must balance the needs and interests of future generations with the needs and interests of those living today. As such, it is not appropriate to discount the future in ways that are commonplace in modern economics. Intra-generational equity should consider the question of where to locate a waste disposal facility and, in so doing, seek to properly handle the needs and interests of spatially separated communities living at the same time as one another. Such thinking led CoRWM to recommend 'community packages' of compensation to communities willing to accept an RW facility but subject to negative externalities such as property blight and disturbance.

As the Nuclear Decommissioning Authority in the UK seeks to implement policy recommendations emerging from the Government in response to CoRWM it seems possible that communities might actually compete to host an RW repository, if the 'compensation' on offer is sufficiently attractive. As such NIMBYism might even be replaced with PIMBYism (Please In My Back Yard or YIMBY (Yes, In My

Back Yard)). Polls have found, for example, stronger support for nuclear power in the vicinity of operating nuclear power plants (e.g. Wikdahl 1991, for the case of Sweden).

It is not unimaginable that, at least for many of the first projects, CCS might relate more to PIMBYism than to more conventional notions of NIMBYism. Such a response seems especially likely where the reservoir in question is a depleted oil and gas reservoir and where the community has hosted oil and gas operations and benefited from employment and built trust in the companies involved. This situation is true of enhanced oil recovery in the Permian Basin in Texas or of acid gas injection in Alberta (Heinrich et al. 2004) as well as the Lacq project in France.

Locations for RW repositories are usually in isolated and economically distressed regions. The former criterion might have a rational basis in the event that the proposed facilities are not as safe as is stated by their proponents. The latter argument is perhaps more compelling, that poor isolated communities lack political influence and hence make it easier for proponents of controversial installations to win the day.

5 Culture, Fear and Iconography

Fundamental to attitudes to RW are attitudes to nuclear technologies generally, including especially nuclear weapons. The interrelationship between the Cold War and the Bomb are culturally resonant, attracting the attention of Stanley Kubrick (Dr Strangelove, 1964), Andy Warhol (Atomic Bomb, 1965), and Salvador Dali (Atomic and Uranian Melancholic Idyll, 1945) among many others (Jones 2002).

The interrelationship between matters nuclear and pop culture extended in time beyond nuclear weapons to include aspects of civil nuclear power such as RW. The timing was such that opposition to nuclear energy followed on directly from previous protest movements, which had followed trajectory in the USA from Civil Rights through opposition to the Vietnam War.

One observer of the 1960s describes the close link between environmentalism and opposition to nuclear power as follows (Morgan 1991, p. 244):

> 'One of the primary early targets of ecological activism was the nuclear power industry. In fact, of all forms of environmental politics, the antinuclear movement was the most directly reminiscent of Sixties activism. With citizens' referenda, lobbying, litigation, and administrative intervention; civil disobedience and other forms of direct action; and mass rallies aglow with countercultural trappings, the antinuclear movement recalled the antiwar movement that had just ended. In its early days, it was largely populated by former peace activists as well as feminists, assorted environmentalists, and counterculture communards.'

It is far from clear whether opposition to CCS would fall naturally into line with a continuous tradition of countercultural protest, although opposition to coal without CCS would seem to have increasingly fallen into that category. For example, as mentioned in Sect. 2, coal-fired power stations have increasingly become the focus for direct action. The Camp for Climate Action, a grassroots movement which originated in the UK, but which has spread across Europe since 2007, has set up camp at UK coal-fired power stations for two of the past 3 years and has sought to engage in various forms of direct action including efforts to shut the plants down or block coal trains (Joyce 2008). In 2007, two major new proposed German coal-fired stations were defeated in local referenda on sites that had previously been occupied by coal-fired generation units.

Ocean storage had already been effectively ruled out as a viable option as a result of the major international experiment being torpedoed by opposition. The project was planned first for Hawaii, where opponents delayed the project and then, when it relocated to Norway, Greenpeace sailed the Rainbow Warrior to meet with the Norwegian environment minister who withdrew permission for the experiment (de Figueiredo 2002).

The primary advocates of CCS—national governments and the energy industry—are precisely those least trusted by the public, especially when compared to high levels of trust in NGOs and independent scientists (EC 2008b). For RW, the reality is that it has been there before, with large-scale protests in, for instance, the 1980s. It seems likely that, by extension, plans for geological disposal of RW will be disrupted by protest, but it is far from certain that they will be. If the counterculturalists of yesteryear are now too old to stand up and protest and they failed to pass their politics to the next generation, then RW developments might progress relatively unimpeded by protest.

One aspect of 1960s protest may continue to echo in today's attitudes to RW and this relates to the attitude of women to nuclear technologies. As noted above, polling reveals that a significantly larger number of women than men oppose nuclear energy. Perhaps the greater tendency for women to have negative attitudes to nuclear technologies is something more intrinsic to these technologies themselves. If so, then this would expose a key difference between RW perceptions and those relating to CCS. Given the low overall levels of awareness regarding CCS it is too early to determine whether there will be any significant gender split.

The thesis that says that the aversion of some women to nuclear technologies is more intrinsic points to observations such as:

- The relationship between radiation and genetic damage tapping into, and arguably subverting, a woman's ability to control her own fertility. Such issues became resonant in the 1960s given the then growing interrelationship between feminism and fertility after the introduction of the contraceptive pill in 1957.
- The emergence of the notion of deep ecology, which posits that mankind is merely a component of a broader living and evolving environment within which it has no special status. This philosophy draws much upon the concept of Gaia developed and popularized by James Lovelock.

It is with the growth of Gaia as a popular construct that the interplay between environmentalism and nuclear energy arguably comes full circle. In The Revenge of Gaia, Lovelock (2006) argues that anthropogenic climate change is a threat to the entire biosphere. In comparison, the risks associated with nuclear energy and RWs are small and manageable.

Fig. 1 Michael Simonian's Plutonium Memorial concept '24110'. (Images copyright Simonian; see: http://www.designboom.com/eng/cool/simonian.html) (*see* Colour Plates). The artist imagines a central Washington DC location for a plutonium store just under the Ellipse, a field 1 km in circumference, near the White House, which takes to an extreme the notion that plutonium storage should not be *out of sight and out of mind*

There is another link between culture and RW that has few, if any parallels, in CCS policy, namely the notion of possible warning signs on RW repositories to protect against the risk of accidental intrusion referred to earlier. The Bulletin of the Atomic Scientists has supported creative responses to this problem with, respectively, the Universal Warning Sign competition (ECYMIO 2003) and the Plutonium Memorial Design Contest, won in 2002 by Michael Simonian with his concept '24110', which takes its name from the half-life in years of the main plutonium isotope Pu-239 (Bulletin of the Atomic Scientists 2002), and which is shown in Fig. 1.

Although often thought benign, at high enough concentration CO_2 may lead to asphyxiation caused by oxygen displacement. Being heavier than air, leakage may lead to accumulation in low lying areas or basements and may therefore pose a minimal threat to local populations in the vicinity of storage sites or CO_2 pipelines. There are a number of natural analogues: CO_2 seeps at Poggio dell'Ulivo in Central Italy discharge 200 t CO_2/day via soil degassing and at least ten people have been reported to have died from CO_2 releases in the Lazio region in the past 20 years (IPCC 2005); in April 2006, at Mammoth Mountain in California, three ski patrollers died while trying to fence off a volcanic vent (USGS 2001; Doyle 2006).

Far more dramatically, in 1986, 1,700 people died after a massive CO_2 explosion at Lake Nyos in Cameroon (Kling et al. 1987). In 1984, a smaller explosion in Lake Monoun, also in Cameroon, killed 37 people. A third lake, Lake Kivu, on the Congo–Rwanda border, is also known to be a reservoir of CO_2 and methane. Accumulation of CO_2 begins when CO_2-rich gas of volcanic origin comes into contact with groundwater, which is then discharged into the bottom of the lake. Before the gas events, these lakes were strongly stratified, such that surface and bottom waters did not mix, thus allowing the gas that was being input in CO_2-charged springs to build up in the bottom waters of the lakes.

The trigger mechanism responsible for the gas release from the lake has been the subject of much speculation. Although there were some claims that there was a volcanic event, it now seems likely that a large landslide entered the lake causing the lake stratification to break down enough to initiate the gas release. Although there is no physical analogue to CCS, to the consternation of CCS advocates, Lake Nyos is often cited as a reason to fear large-scale storage of CO_2 (Brown 2007). Given the low level of public awareness of CCS in the first place, this fear-mongering is unlikely to have had much influence on the public to date, but it remains one element of the arguments put forward by groups opposed to CCS (Rochon 2008).

6 Conclusions

So how does public acceptability of RW disposal compare to that for CO_2 storage? In some respects, it is nonsensical to provide an answer at this stage when less than 10% of the public in most countries have even heard of the concept of CCS and when there are no full-scale operating CCS projects. Nevertheless, there are some reasons to believe that CO_2 storage is fundamentally less controversial. The need for many storage sites avoids the painful debates over equity associated with choosing a single national storage site. The sheer volume of CO_2 from a single large coal-fired plant requires resolution of any local (or national) concerns long before a project starts whereas the tiny volume of RW means that final decisions on ultimate disposal can be, and have usually been, deferred for not just years, but many decades. The inextricable association of RW with nuclear power and the potential for meltdown and with nuclear weapons and security concerns such as proliferation imbues the subject with dread fear of a nature that is rare for any subject. Although there are some such fear-inducing associations with CO_2 storage such as the disaster at Lake Nyos, most people commonly relate CO_2 to exhaling and to the uptake of CO_2 by trees and other vegetation. CO_2 is something familiar and, as such, largely uninteresting even if the phase concerned is liquefied and at high pressure. Conversely, all matters nuclear, including RW, are unfamiliar, so perhaps it is ironic, but in part as a result of its exotic nature, nuclear issues have become part of our popular culture and are often regarded with great interest.

Table 1 summarizes some of the main themes that have emerged in this chapter. Controversies over local siting, the links to the associated energy technology and trust in the actors providing information and communicating with the public are the issues that bear the greatest similarities across the two areas but, with the exception of the actors involved, even these broad similarities are quite different in practice because of differences in attitudes towards coal and nuclear power and the likelihood of a single onshore repository for RWs versus multiple CO_2 storage sites that might be onshore or offshore. As noted above, it is the nature and history of the two subjects that result in the greatest differences. Attitudes towards RW are well monitored and unlikely to change other than marginally bar a major event, whereas opinions on CCS and CO_2 storage have only been studied for a few years and the public remains largely ignorant. Even those opinions voiced in current surveys are unlikely to be stable and will depend on the framing and evolution of CCS as the first demonstration plants are funded and launched.

Table 1 Comparison of key attributes associated with public acceptance of CO_2 storage and geological disposal of radioactive wastes

Subject	Radioactive waste disposal	CO_2 storage
Public awareness	Broad public awareness	Minimal public awareness of any aspect of CCS
Public understanding	Generally weak in spite of high awareness	Basic understanding of carbon cycle but minimal to none on CO_2 storage itself
Public acceptability of solution	Acceptability poor and greater acceptance not necessarily linked to greater understanding	Linked to climate change and perceived adequacy of other solutions, but still too early to determine
Demographics	Strong female opposition across time and region	Little evidence of major differences visible at this stage
Timing	Not necessary to address immediately; in most cases deferred for decades	Essential to resolve storage before operation begins because of volume of waste stream
Risk communications	Extensively studied but practice remains weak	Few examples of good practice, poorly studied
Trust in actors	Involves energy industry and government, some of least trusted actors in society Eroded by image of 'nuclear priesthood'	Involves energy industry and government, some of least trusted actors in society
Views of grassroots and environmental NGOs	Generally hostile although there has been successful engagement on narrow question of repository siting	Main environmental groups are neutral to moderately positive Some resistance from grassroots groups less concerned with climate change alone
Support for associated energy technology	Support for nuclear power remains divided and this division has continued for decades	Unabated coal is becoming increasingly unpopular, although there remains support for coal miners in many countries

CCS Carbon capture and storage, *NGO* Non-governmental organization

It is interesting to consider why the RW problem has been so difficult. One compelling idea is that the RW problem is an example of a *wicked problem* (Conklin 2006). Such problems are characterized by an odd circular property that the question is shaped by the solution. As each solution is proposed it exposes new aspects of the problem. Wicked problems are not amenable to the conventional linear approaches to solving complex problems. Linear approaches go from gathering the necessary data, through analysing the data and formulating a solution, towards implementation of a final agreed solution. By contrast, wicked problems can at one moment appear to be on the verge of solution, yet the next moment the problem has to be taken back to its complete fundamentals for further progress to be made. As such, any opinion that the problem is almost solved is no indication that it actually is. Wicked problems can persist for decades and, for a true wicked problem, no solution will ever be possible. Wicked problems typically combine technical factors and social factors in complex multi-attribute trade-offs. A problem that is not wicked is said to be 'tame'. A key question for consideration by the CCS community is whether they too have found themselves in a similar situation. The key difference, as noted earlier, is that if there is no resolution to concerns over CO_2 storage there will be no possibility for large-scale implementation of CCS to proceed.

According to MacKerron (2004), nuclear power has not merited the same government support as renewables because of the associated non-climate change externalities. The economic and, especially, political risks of nuclear power are perceived as balancing its climate advantages from being a low-carbon source of electricity. MacKerron then lists a series of ways in which nuclear power might become 'ordinary' and hence more attractive to private investors, chief among these being 'resolution, to the satisfaction of the wider public, most stakeholders and any affected local communities, of the radioactive waste management problem.' A similar question for CCS is whether it might command subsidies needed to allow for construction of the first tranche of large-scale projects. The future of fossil-fired generation is therefore wrapped up in questions both of the fuels themselves but also of the ultimate fate of CO_2 underground. As described above, nuclear power and RW have never been perceived as 'ordinary'. Although CO_2 storage is still unfamiliar to the vast majority of the public, the familiarity with CO_2 itself and its comparatively benign nature may allow CO_2 storage to proceed even though individual CO_2 storage projects may well be halted for a variety of NIMBY or other local considerations much as would be the case for many other types of waste facilities.

Acknowledgements This work is supported through a contract with the International Atomic Energy Agency. We would like to thank Ferenc Toth for his support and his helpful comments as well as for those of two anonymous referees.

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