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

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Abstract

Physically, geological storage of carbon dioxide (CO2) and of nuclear waste are fundamentally different problems in terms of scale and toxicity. The political and social differences are equally stark -- consider the almost complete lack of awareness of CO2 storage versus the highly-charged political debates over storage of radioactive wastes and the exceptionalism of nuclear in the broader cultural and political context. Nevertheless, there are some notable similarities, including the difficulty of extricating not-in-my-backyard (NIMBY) behaviour from other concerns, the inability to divorce the politics of waste streams from the underlying electricity generating technologies, the highly technical nature of both issues and the role that both CO2 storage and nuclear waste play in the larger debate over energy policy, particularly as a proxy issue for non-governmental organisations (NGOs). Surveys of public attitudes with respect to geological storage are reviewed and the role of NIMBY and compensation to local communities in facilitating the siting of storage facilities are assessed.

Keywords Public attitudes; Geological disposal; CCS; CO2 storage: nuclear waste; NIMBY; energy policy

JEL Classification Q4; Q53

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

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1. Introduction

The differences between storing carbon dioxide (CO_2) underground and nuclear waste storage would seem, on its face, to be enormous, both technically and with respect to the attitudes of both local communities and the wider public.

The scale differences and levels of experience are striking. A 1000 MWe light water reactor will generate 200 - 350 m^3 of low and intermediate level waste per year and $20m^3$ (27 tonnes) of used fuel per year (WNA, 2008a). 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 a similar size will produce some 7 million tons of CO_2 per year. To date, the largest CO_2 injection sites of roughly 1 million tons 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 carbon dioxide capture and storage (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. 1 Gt C (~3.6 Gt CO2) is equivalent to capture from 600 1-GW plants and would require the equivalent of 3600 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 very large scale; as of April 2008, there

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were 392 GW of nuclear power in operation (ENS, 2008). That electrical energy, if supplied from fossil fuels, would yield emissions on the order of 1Gt C.

Although difficult to compare easily, by any measure, the toxicity also differs by many orders of magnitude. CO_2 is one of the least toxic compounds known, although at high concentrations it acts as a simple asphyxiant. Air normally contains 0.03% CO_2, at 2.5-5%, concentrations headaches and upper respiratory problems may result, at 10% unconsciousness within one minute and at 20% respiratory arrest. The Threshold Limit Value is set at 0.5% or 5000 ppm (Kent, 1998). By contrast, the existence of threshold effects for radioactive wastes 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 also would appear vastly different. High-level nuclear waste in particular has been the subject of intense debate, usually at the national level and has often continued unresolved for decades. 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).

Aside from the implications of CCS for the larger debate over climate change, the future of coal and decentralised generation, the physical characteristics of CO_2 would seem to lead to far more local (and far more frequent) debates over siting. Nuclear waste 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 nuclear waste 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. 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 NGOs, and the basis for local opposition or support.

It is also important to mention the terminology involved, which reflects, in part at least, the image that proponents wish to generate. In the case of nuclear waste, "storage" is used to describe an interim measure, often above ground, where the wastes are subject to human oversight and monitoring. "Disposal" of nuclear wastes 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 sealed for eternity. 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 nuclear wastes, whereby the CO_2 is stored in a deep geological reservoir and monitored for an extended period during the injection and post-injection phases. Unlike nuclear waste management, which uses a multi-barrier approach since the small quantity of radioactive is normally encapsulated, 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. Thus, analysis of CO_2 storage has focused on the different trapping mechanisms by which the CO_2 will be secured in place as part of the formation such that after monitoring for several decades, geologists could be assured that the CO_2 would be trapped without the need for continuing oversight. Throughout, we maintain the convention of referring to CO_2 storage and nuclear waste disposal.

We divide our analysis into four parts: (i) 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; (ii) general public opinion on the subjects; (iii) the role of NIMBY ('Not In My Back Yard') and compensation to local communities in facilitating the siting of storage facilities and finally, (iv) the extent to which culture, fear and iconography influence public perceptions and political debate.

2. History, Energy Choices and the views of NGOs

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 thirty 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 WWII led radioactive waste 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 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.

In the years after WWII 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:

> "*… no commitment should be made to a large programme of nuclear power until a safe method for the containment of radioactive wastes had been demonstrated*" (RCEP, 1976).

In this way 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 nuclear waste question unanswerable. There is a certain irony in this aspect of the legacy of the Flowers Report. The Royal Commission seemingly intended that its emphasis on the pressing need for institutional and technological solutions to the waste problem would act as a spur to policy progress in that important area. At least initially it did, as there is a direct line between its recommendations and the creation of the former UK waste management body NIREX. However, what was intended to act as a spur to advance waste management as a top priority (because of real issues of concern in that regard) arguably led to the wider development of nuclear energy becoming a secondary concern. That de-emphasis was never the intention of the Commission. 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 as an issue (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, 2008b).

In this way radioactive waste became the *Achilles' Heel* of nuclear power. In such a paradigm radioactive waste 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.

As technologies of the late twentieth century nuclear energy and nuclear waste management have a special place in the sociology of scientific knowledge (SSK). A key part of SSK has related to public perceptions of risks and the acceptance of technology. Sociologists, such as Brian Wynne, have pointed to the benefits of seeing technology as a social organization (Wynne, 1998).

Wynne observes:

> *One important development in the social position of science has been the pressure to open the established 'black box' of scientific knowledge-products in areas of public controversy such as risk analysis, and to examine more critically the internal processes which have produced conflicting scientific claims. […]*
> *The policy field has been dominated by 'black box' concepts which treat technology as autonomous and 'internally' unproblematic, or at best, the non-social domain of technical experts. In this conception, technologies are evaluated by their external effects or risks alone, and not by the relationships which may be intrinsic to them. On the other hand, concepts of technology as social organization have been far less influential. Such concepts imply the*

> *need to examine the forms of social organization, as well as the technical design, needed to ensure technology's overall viability.* (Wynne, 1988)

Wynne posits that it is impossible to disentangle a technological system from its social context. He does not assert that technology is merely a social phenomenon and he reminds us that 'contextualization' cannot be assumed to encompass the full scope of a technology. Wynne and others posit that a key failure in the development of nuclear energy has been the failure of policy makers to give proper consideration to contextual issues and that arguably there has arguably been a failure to secure 'social legitimacy' for this technology.

Wynne's contextualism sits in a wider landscape of SSK that on one extreme regards science and technology as socially constructed and at the other a 'realist' or even positivist tradition giving emphasis to the 'scientific method' alone. This wider landscape includes the notion of contextual 'mode 2' knowledge developed by Gibbons and co-workers, in direct contrast to the 'Newtonian' approach which they term 'mode 1' (Gibbons, 1994). This landscape between the 'constructionist' and the 'realist' has been reviewed by Burningham and Cooper (1999). Burningham and Cooper challenge several misconceptions concerning constructionism and point out that it is to be viewed as an approach that denies the existence of facts or the existence o reality. They argue that constructionism simply gives emphasis in other directions: particularly stressing the importance of 'claims' in the handling of environmental issues. Truth and facts exist, but often they are of secondary importance.

Grimston (2008) has posited that in the 1960s the UK government handed not only the implementation of nuclear policy to the technologists, but also the development of policy itself. The issues of nuclear energy were scientifically and technologically complicated and, in the short-term at least, it was easier to pass these issues to those that 'understood them'.

Wynne suggests that social legitimacy is obtained at the expense of the power of the technical experts and indeed in so doing the very notion of the expert would become more complex and differentiated. In this paper we note that the length of a journey is a function of both the point of departure and the point of destination. For nuclear energy and nuclear waste management the journey towards social legitimacy is a long one and it is not complete. In the case of CCS there is perhaps an opportunity for those involved in these early days to choose the point of departure for their journey. If a contextualist approach is adopted from the start, then that journey could be very short indeed, in contrast to the nuclear energy experience.

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, whether a situation might develop by which 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, which is dominated by the costs of capture (IPCC, 2005).

Resolving the ongoing debate over long-term liability will also be essential to the financing of CCS (de Figueiredo, 2007). Experience from the radioactive waste 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 nuclear waste 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., Ray and Farrell, 2008). In the US, support among NGOs is also combined with the drive for greater use of IGCC 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).

Many European NGOs, are more concerned (than other stakeholder groups) at the possibility of increased focus on CCS diverting public resources away from renewables (Shackley et al, 2007). NGOs 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.

CCS, although largely unfamiliar to the majority of publics, 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 the 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 tons of CO_2 in its first years of operation rather than full-scale capture (which would be roughly 1.3 million tons CO_2) and the project has since decided to simply release the CO_2 to the atmosphere (Berglund, 2007).

Other countries where CCS have played an increasingly important role in national energy and climate policy include Australia, the Netherlands, US, 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 US and Australia, the two largest coal producers in the developed world, CCS is intimately tied to the continuation of coal-fired electricity generation. 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 1.6 GW coal-fired plant at Kingsnorth in the UK has come under fire from the Royal Society, over 200 MPs and activists in the Camp for Climate Action (Adam and Macalister, 2008).

One important distinction between radioactive waste and carbon dioxide is that radioactive waste is not a single well-characterised entity. Even before WWII, industrial activities involving radioactive materials had already generated significant volumes of materials equivalent to radioactive waste. Examples of harmful materials that predate capture by radioactive waste 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 radioactive wastes 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 radioactive wastes in addition to the various science-based issues and hazard-related considerations that necessarily affect such processes.

There are numerous classifications of radioactive waste 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 many countries have LLW disposal facilities. Of these British formal classifications of radioactive waste HLW and ILW are defined so as to suit the output streams of aqueous nuclear fuel reprocessing.

Britain and France as two leading countries with a history of nuclear fuel reprocessing, both possess substantial inventories of HLW, ILW and LLW. It is noteworthy that the French have been more effective in minimising the quantities of ILW generated, albeit with consequences for HLW management. Classification is important to radioactive waste policy and in the UK it is interesting to note that separated plutonium, spent fuel and depleted uranium are not officially radioactive wastes, although recent policy processes (such as the UK Committee on Radioactive Waste Management) have started to give these materials full consideration.
Other countries such as Sweden and the United States operate a once-through fuel cycle and in these countries spent fuel is a waste for disposal in facilities in Åspo and Yucca Mountain, Nevada respectively. The relative merits of the two fuel cycles are

too complex to explore here. Suffice to say that any differences of long-term safety and environmental protection, are relatively small but they do result in differences concerning the details of waste management options (WNA, 2008a).

In both cases the dominant paradigm is deep 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 have, however, in many cases motivated significant work into surface and near-surface managed storage options, albeit usually merely as an interim measure. Such measures can, however, last for many decades.

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 (Andra, 2008).

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

Threats to a radioactive waste repository fall into two classes. The more conventional issues relate to natural processes of geology and hydrology, together with the materials science of immediate waste encapsulation. These natural processes determine whether harmful radio-nuclides will be released and by what means, 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 of thousands of years or more. The second class of threat is more difficult to analyse and it concerns 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 a nuclear waste 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-industrialised world mighty intrude on a radioactive waste 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. The timescales and the risks of deliberate and accidental intrusion into sequestered radioactive waste or carbon dioxide 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. Paul Klemperer is one commentator that has pointed out that conventional economic tools of discounting under value the needs and interests of future generations. By implication much smaller, or perhaps even negative, discount rates should be considered. A countervailing input comes from public attitudes surveys which have supported the advice of Charles Galton Darwin "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: 307).

Even more so than for nuclear waste, 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, Caldeira, and Reilly, 2003). Aside from localised effects, such as migration to someone's basement, leakage is of concern because it will add to the atmospheric burden of CO2 and thereby reduce the effectiveness of CCS. Of course, the British Geological Survey has argued that currently leakage from fossil generation is effectively 100% (HoC, 2006: Ev70)

3. Demographics and Opinion

Data from Eurobarometer surveys reveals quite stable patterns in public attitudes to radioactive waste (EC, 2005c; EC, 2008b). 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 radioactive waste, whereas for those averse to nuclear energy 79% report being poorly informed on radioactive waste. 71% of Eurobarometer respondents correctly understand that there are several types of radioactive waste but tellingly 78% incorrectly believe that all types of radioactive waste are very dangerous, which is roughly the same level as surveys conducted in 2001 (EC, 2002) and 2005 (EC 2005c).

Although almost all Europeans (93%) believe there is an urgent need to finding a solution to radioactive waste now, rather than leaving it unsolved for later generations, over 70% do not believe there is any safe way of getting rid of high level radioactive waste (EC 2008b). Deep underground disposal is seen as the single most appropriate solution for managing high level radioactive waste 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 2005a; Reiner et al, 2006).

Information does not necessarily bring support. Three quarters of Europeans in the 2005 and 2008 Eurobarometer on Radioactive Waste, felt that they were "not well informed" about nuclear waste (EC, 2005). Moreover, 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 high level radioactive waste" (EC, 2008b). 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 that are expert in its intricacies, which further calls into question the "deficit model" view of science (Sturgis and Allum, 2004). Such anecdotal observations prompt us to question whether the observed correlations are causal. Are women more nervous about nuclear power and nuclear waste because they know less about it? Furthermore do they know less about nuclear matters because they are less likely to have studied physics and maths in school? Is the "gender" aspect of public attitudes to nuclear waste merely a reflection of more fundamental sociological or perhaps socio-biological issues relating to teenage girls and boys and their interests in school?

Public attitudes to radioactive waste 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 54%. 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 also are generally less well informed about the issues (57% of the men answered the Eurobarometer 227 report questions correctly compared to 50% of women) although men are also more likely to answer incorrectly, women are more likely to respond "don't know". Women are also less likely to favour deep underground storage (37% versus 49% for men) and less likely to believe that nuclear power allows for diversification of the energy supply (57% vs 72% for men). 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, Slovic and Mertz (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.

By contrast, at a basic level, the lay public has a quite good familiarity with carbon dioxide. 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 nuclear waste storage and studies in various countries finds there is very little awareness of the 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 waster pollution (ibid). Similar results have been found in opinion surveys in Spain and in Australia.

The major concern voiced in focus groups (Shackley, McLachlan, and Gough, 2005) was concern over leakage of carbon dioxide 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 is considered to be relatively low risk (Shackley et al 2007). NGOs tend to view both CCS and storage in particular as somewhat riskier, although the major concern expressed is over the additional fossil fuel use necessary because of the energy penalty in the capture process, followed by human health and safety from onshore CO_2 storage and environmental damage from both onshore and offshore CO_2 storage.

4. Location, NIMBY and Compensation

Siting nuclear waste facilities has proven exceedingly difficult around the world. Efforts at siting often face concerns on the grounds of equity and process as much as on risk and technical considerations. As Gerrard (1996) notes in the context of the United States, "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, 4).

The Facility Siting Credo (Kunreuther, Fitzgerald, and Aarts, 1993) offers a series of suggestions on how to successfully site a major infrastructure project: (i) instituting a broad-based participatory process, (ii) seeking acceptable sites through either a volunteer or a competitive siting process; (iii) keeping multiple options open at all times; (iv) guaranteeing stringent safety standards; (v) ensuring geographic equity; and (vi) making the host community better off. Most national-level processes aimed at choosing a radioactive waste site have been unwilling or unable to comply with many of these recommendations (e.g., competitive siting, geographic equity, keeping many options open). Though there are few existing examples of siting CO_2 storage facilities near a concerned community, the diffuse nature of CO_2 storage inevitably means that it will be easier to meet some of the elements of the credo than is the case for nuclear waste.

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 United States (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 (2007) of the potential for compensation in the case of CCS is largely skeptical 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, Midden, and Meijnders (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 carbon dioxide. 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, Lofstedt and Cvetkovich 1999).

Wong-Parodi., Ray and Farrell (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 1001 Nevada residents, Kunreuther et al (1990) found 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 $1000-$5000 in rebates per year for 20 years is 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.

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 radioactive waste in that from the outset it was not constructed to be simply a scientific and technical problem. CoRWM recognised from the outset that it was as much a sociological and political problem. In addition to issues considered by previous policy-making bodies CoRWM devoted much energy to what the committee termed "ethics", and in particular "intra and inter generational ethics" (CoRWM, 2006). CoRWM suggests that inter-generational 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 properly to 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 a radioactive waste 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 a radioactive waste 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, Herzog and Reiner, 2004) as well as the Lacq project in France.

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

The inter-relationship between matters nuclear and pop-culture extended in time beyond nuclear weapons to include aspects of civil nuclear power such as radioactive waste. The timing was such that opposition to nuclear energy followed directly on from previous protest movements, which had followed trajectory in the United States 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:

> *"One of the primary early targets of eco- logical 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."* (Morgan, 1991: 244)

It is noteworthy that CCS still lacks an iconography and a position within mainstream pop culture. It is also far from clear whether opposition to CCS would fall naturally into line with a continuous tradition of counter-cultural protest, although opposition to coal without CCS would seem to have increasingly fallen into that category. Ocean storage had already been effectively ruled out as a viable option even before basic experiments could be done on the subject (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, 2008a). For nuclear waste, 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 radioactive waste will be disrupted by protest, but it is far from certain that they will be. Are the counter-culturalists of yesteryear now too old to stand up and protest? Have they failed to pass their politics to the next generation? If so, future radioactive waste developments might progress relatively unimpeded by protest.

One aspect of 1960s protest may continue to echo in today's attitudes to radioactive waste 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. We have considered whether the route to this could lie in a lack of understanding of the science and technology. Such a thesis is known as the "deficit model" in studies of public attitudes to science and technology. As a thesis it is widely criticized (Sturgis and Allum, 2004). Perhaps the logical links explored earlier are incorrect and in fact 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 radioactive waste perceptions and those relating to CCS. Given the low overall levels of awareness regarding CCS it is too early to determine whether there is any significant gender split.

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

- 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 inter-relationship between feminism fertility after the introduction of the contraceptive pill in 1957

- The growth of the notion of eco-feminism, the interplay of ecological and feminist goals first posited by Françoise d'Eaubonne in her book Le Feminisme ou La mort
- 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 radioactive wastes are small and manageable.

There is another link between culture and radioactive waste that has few, if any parallels, in CCS policy, namely, the notion of possible warning signs on radioactive waste 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 (Nuclear Waste Update, 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).

Figure 1. Michael Simonian's Plutonium Memorial concept "24110" imagines a central Washington DC location for a plutonium store just under the Ellipse near the White House, which takes to an extreme the notion that plutonium storage should not be *out of sight and out of mind*.
[Images copyright Simonian – clearance required – see: http://www.designboom.com/eng/cool/simonian.html]

Though often thought benign, at high enough concentration, CO_2 is toxic separate to any dangers of 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 /day of CO_2 from soil degassing and at least 10 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, 1700 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 carbon dioxide and methane. Accumulation of CO_2 in the lake begins when CO2-rich gas of volcanic origin comes into contact with groundwater, which is then discharged into the bottom of the lakes. Before the gas events these lakes were strongly stratified, such that surface and bottom waters do not mix, allowed 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 its relation to CO_2 storage is tenuous, Lake Nyos is often cited as a reason to fear large-scale storage of CO_2 (Brown, 2007).

6. Conclusions

It is interesting to consider why the radioactive waste problem has been so difficult. One compelling idea is that the radioactive waste problem is an example of a *wicked problem* (Conklin 2006). Such problems are characterised 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 given the scale of CO2 that needs to be disposed of from even a single plant, CCS requires a satisfactory solution to the storage problem before large-scale implementation is possible. Unlike the nuclear case, if there is no resolution to concerns over CO_2 storage there will be no possibility for large-scale implementation of CCS to proceed.

MacKerron (2004) has noted that nuclear power has not received the same government support as renewables because its non-climate change externalities impose economic and, especially, political risks that are perceived as balancing the 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 nuclear 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 carbon dioxide underground. As described above, nuclear power and nuclear waste have never been perceived as "ordinary" and although CO_2 storage is still unfamiliar to the vast majority of the public, the familiarity with carbon dioxide itself and its comparatively benign nature may allow carbon dioxide 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.

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