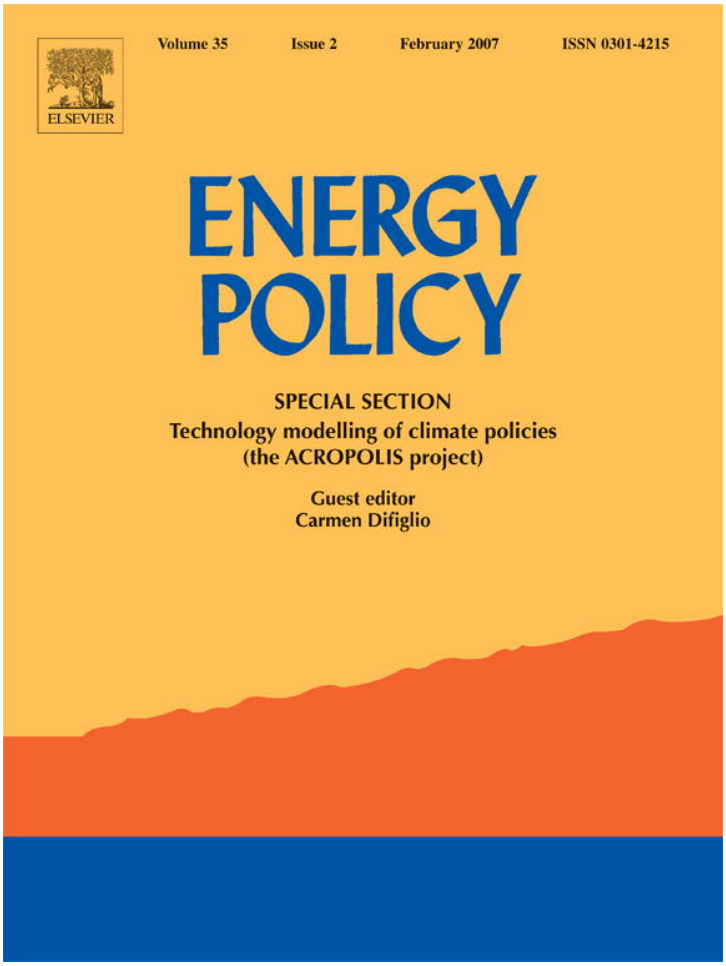

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Viewpoint

CO_2 capture and storage: Another Faustian Bargain?

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Abstract

A quarter-century ago, one of us termed the use of nuclear energy a Faustian Bargain. In this paper, we discuss what a Faustian Bargain means, how the expression has been used in characterizing other technologies, and in what measure CO_2 capture and storage is a Faustian Bargain. If we are about to enter into another Faustian Bargain, we should understand the contract.

Keywords: Faustian Bargain; CO_2 capture and storage; Philosophy of science

Alvin M. Weinberg passed away on 18 October 2006, a few days after this paper was submitted to Energy Policy.

Alvin Weinberg is known to many as the father of the light-water reactor and as a promoter of nuclear energy—from the days of the 1955 UN Conference on the Peaceful Uses of Atomic Energy—and as the long-time director of Oak Ridge National Laboratory. Many also know that Alvin Weinberg was a pioneer in the area of nuclear safety. He early on stressed the need to improve the safe disposal of radioactive waste and to design safer and more proliferation-proof reactors.

To us Alvin was our teacher and role model, a brilliant, inquisitive mind and a generous friend. His desire to know things precisely and to keep posing questions scared many of his co-workers, but it spurred us to do our homework thoroughly before we came across Alvin. As our boss at the Institute for Energy Analysis in the 1970s and 1980s, he was keen to understand the entire energy system, from the role of OPEC to energy conservation and, last but not least, to climate change. He knew that suitable institutional arrangements and solid intellectual and philosophical foundations mattered.

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A good text to get to know his work is: Alvin Weinberg, ''Nuclear Reactions: Science and Trans-Science'', American Institute of Physics (Masters in Modern Physics), 1992.

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1. Introduction

Carbon dioxide capture and storage (CCS) describes a technological strategy that promises to let us continue to use fossil fuels without increasing the atmospheric concentration of carbon dioxide (CO_2) and changing the Earth's climate. CCS recognizes the importance of fossil fuels to society and that CO_2 is an essential product of burning them. But CCS suggests that the CO_2 from fossil-fuel burning need not necessarily be discharged to the atmosphere. The CO_2 can be captured at its point of generation at power plants and other large sources and placed somewhere other than in the atmosphere. It might be coaxed into the biosphere, injected into the ocean, or, as often cited, injected into 'geologic reservoirs'. Geologic reservoirs might be exhausted reservoirs from which oil and natural gas have been recovered, they might be unmineable coal beds, or they might be deep rock layers containing saline waters and of no commercial value.

CO_2 capture and storage has in recent years been increasingly heralded as perhaps the least costly solution to global warming. The enthusiasm with which it is received resembles the optimism that accompanied the introduction of nuclear power for commercial power generation. And it bears some technological resemblance to nuclear power, the generation of a waste that needs to be managed for a very long time.

Carbon dioxide is not, to be sure, a dangerous waste in the sense that nuclear wastes are dangerous. Carbon dioxide is a normal constituent of the atmosphere and of human breath. It is safely used in a wide variety of industrial applications, from food preservation to fire suppression. Carbon dioxide exists in the Earth's atmosphere at 385 parts per million and it is dangerous to humans only at ambient concentrations greater than about 3%, and it must be safely managed to avoid such concentrations. Management is also necessary to prevent climate-changing concentrations in the Earth's atmosphere, and it is here that there is no gain unless the CO_2 is kept out of the atmosphere for a very long time. There is, in fact, a net loss if CO_2 is captured and stored but then leaks back to the atmosphere. The capture and storage of CO_2 requires considerable amounts of energy, and much of this energy is likely to be supplied by the burning of fossil fuels. If we need the energy from one unit of fossil fuels and want to capture and store the carbon dioxide generated from burning it, we might have to burn 1.1–1.4 units of fossil fuel in order to get the desired energy plus enough extra energy to capture and store the CO_2 produced.

In a paper written a quarter-century ago one of us (AMW) cautioned against discounting the vigilance required to safely store nuclear waste for very long time spans, describing the predicament as a Faustian Bargain (Weinberg, 1971). In this paper, we discuss what a Faustian Bargain means, how the expression has been used in characterizing other technologies, and in what measure CO_2 capture and storage is a Faustian Bargain. If we are about to enter into another Faustian Bargain, we should understand the details of the contract.

2. Faust

Goethe's (1759–1832) play 'Faust' (published in two parts, in 1808 and posthumously in 1832, respectively) grew out of a rich history of tales in which scientific/technological progress was associated with pacts with the devil. One such tale refers to the building of a bridge over a deep gorge, the Schöllenenschlucht. The bridge served as an essential link in the main route over the Alps at the Gotthard Pass. This bridge was such a technological wonder that medieval travellers believed it had to have been built with the help of the devil. According to the tale, the builders promised the devil, in return for his help, the soul of the first user of the finished bridge. However, before anyone else was allowed to cross it, the clever locals herded a goat over the bridge.

Paracelsus, the great innovator of medical practice in the 15th century, grew up a 100 ft away from another such bridge, near the monastery of Einsiedeln. This bridge, like the bridge over the Schöllenenschlucht, is still called the Devil's Bridge today. Paracelsus learned much of his medicine on travels that took him not only all over Europe, but also to Constantinople and as far as China. Many of his contemporaries saw in the healing power of his medical expertize the intervention of a supernatural, devilish power. Tales of the life of Paracelsus are said to be one of the important sources for Christopher Marlowe's play, 'The Tragical History of Doctor Faustus'. Goethe's 'Faust', in turn, was in part based on Marlowe's play.

In Goethe's play, Faust is assisted and put up to mischief in his endeavors by the devil. This assistance is arranged over the course of the discussion of a number of contract-like arrangements: In the Prologue, Mephistopheles (the devil) suggests to God an experiment with a virtuous human being named Faust. Mephistopheles claims that it will be easy for him to make Faust forget his striving in return for an easy life on Earth. God, reluctantly, agrees to the experiment, knowing that Mephistopheles will fail in his attempts.

Interestingly, Mephistopheles does not explicitly suggest to God a deal that goes beyond Faust's death. This would be too irreverent towards his master, even for Mephistopheles. God, on his part, does not enter into a contract with anyone else, this would mean to step down to the level of the contract partner. So this preliminary discussion is not a bet or bargain, but in a sense it is part of the "Faustian Bargain".

In Part I of Goethe's play, Mephistopheles offers Faust a bargain similar to the one that the bridge builders and other innovators were thought to have accepted. His offer, however, is not the experiment he has discussed with God. Mephistopheles suggests to Faust a bargain, his services here on Earth in return for Faust's soul (Goethe, a)

I'll pledge myself to be thy servant here,
Still at thy back alert and prompt to be;
But when together yonder we appear,
Then shalt thou do the same for me.

Faust accepts Mephistopheles's services, leaving open, however, his fate after his death. Instead he offers to make a bet:

If e'er upon my couch, stretched at my ease, I'm found,
Then may my life that instant cease!
Me canst thou cheat with glozing wile
Till self-reproach away I cast, –
Me with joy's lure canst thou beguile
Let that day be for me the last!
Be this our wager!

Literary scholars have debated at length what the wager was or whether a bargain was struck. Reading the text, much is left open. We see the two interchanges with the four statements as one, contradictory arrangement, called the "Faustian Bargain". Quoting the economist Hans-Christoph Binswanger, the essence of the bargain is that Mephistopheles helps Faust to overcome time, to become immortal by being part of eternal progress, while Faust promises never to rest and never to pause striving for further progress (Binswanger, 2005).

Immediately after the above interchange between Mephistopheles and Faust, Mephistopheles starts to work for Faust. The first advice Mephistopheles offers the depressed Faust is to spend more energy. Faust complains:

I feel it, I have heap'd upon my brain
The gather'd treasure of man's thought in vain;
And when at length from studious toil I rest,
No power, new-born, springs up within my breast;
A hair's breadth is not added to my height,
I am no nearer to the infinite.

Mephistopheles suggests energy and speed, the purchase of six horses, as a remedy:

The devil! thou hast hands and feet,
And head and heart are also thine;
What I enjoy with relish sweet,
Is it on that account less mine?
If for six stallions I can pay,
Do I not own their strength and speed?
A proper man I dash away,
As their two dozen legs were mine indeed.

Thus, the effortless consumption of purchased energy is Mephistopheles's first attempt to gently lead Faust as he, Mephistopheles, chooses.

In Faust II, energy and resources are of central importance. Prompted by Mephistopheles's whisper, Faust advises the emperor to multiply his might by exploiting the natural resources of his country (Goethe, b):

Are there not always wants, the wide world o'er?
Now this, now that, but money in our case;
Which, truly, can't be picked up off the floor,
Yet wisdom delves in treasure's deepest place.
In mountain-veins, old walls, or underground,
Is gold, un-coined or minted, to be found.
And should you ask who'll bring that store to light:
'Tis he endowed with Mind and Nature's might.

The restless striving for more power and success derived from knowledge, energy, and other resources; along with the striving for unattainable perfection in love and virtue; are the main themes of Faust II. This Faustian drive is described as an essential element of human existence. It creates wars and suffering, but it is essentially human in the Faustian sense to live for continuous progress.

In the end Faust's soul is not left to the devil. The angels, carrying Faust's remains up into heaven, sing:

For he whose strivings never cease,
Is ours for his redeeming.

Faust scholars are in disagreement, whether this means that Faust lost his soul or not. In any case, it is not the only choice men and women have for leading a human existence. In Faust II, Philemon and Baucis, an elderly couple taken from Greek mythology, are living in a small house that is to be flooded by one of Faust's hydrologic engineering projects. They live in their small house, are happy with how they live, make do with what they have, and share their humble means with every passer-by (Binswanger, 1994). In their futile resistance to the engineering project, the couple plays the counterpart to Faust. They represent another choice of an admirable human existence, perhaps with less influence on the course of development.

3. Nuclear energy and some other Faustian Bargains

Some years ago, one of us termed nuclear energy a Faustian Bargain (Weinberg, 1971). The image has been used and the phrase quoted over and over again, both because the term was well chosen and because, very often, it has been misunderstood.

The two elements of the Faustian Bargain were both present in the early nuclear enterprise: the temptation of the easy, carefree life it offered (electricity too cheap to be metered), and the bargain it struck (continuous striving was promised). The service electricity provides could be used to pursue progress in all kinds of ways, as long as the obligation was kept to look after the nuclear waste (and, for that matter, other fissionable material as well). If the obligation were shirked, it could, in an extreme scenario, mean the end of humankind.

The phrase Faustian Bargain was also misunderstood. The same year that Weinberg's paper appeared in Science (1972), John W. Gofman wrote an article in which he painted a sketch of what was needed, institutionally, to keep nuclear waste safe (Gofman, 1972). Not only was there a need, in Gofman's view of the Faustian Bargain, for

a perpetual institution (like a priesthood) to look after these wastes, but also everyone had to bow to the whims and wishes of this institution. In other popular publications, the Faustian Bargain was presented not as a human condition, but as a devilish complot by one group of humans to enslave the rest.

The term Faustian Bargain has been used during the subsequent years to characterize many 'technological fixes' of immediate problems with potential negative long-term consequences. Here are several examples of such fixes and their consequences:

- The Comprehensive Test Ban Treaty on nuclear weapons was seen by conservative analysts as a quick fix that reduced US vulnerability to attack with nuclear arms, but posed the long-term risk of leaving it defenseless (Eland, 1999).
- Stockpile stewardship of nuclear weapons was seen by lawyers on the liberal side of the political spectrum as a quick fix for keeping some nuclear weapons in good shape, and maintaining some defense capability, but risking that in the long-run the Comprehensive Test Ban Treaty would not be sufficiently implemented (Lichterman and Cabasso, 2000).
- Taking pain-relieving drugs such as NSAIDs,[1] which help reduce joint inflammation, may have long-term effects (Peloso, 2000). In the longer run, NSAIDs may cause serious upper-gastrointestinal complications, and many COX-2 inhibitors, a related, common class of prescription pain-relievers, have recently been recalled due to serious side effects, including heart attack and stroke.
- The practice of routinely performing Cesarean deliveries on high-weight babies has been questioned (Rouse and Owen, 1999). One immediate risk (brachial-plexus injury at birth, observed in less than one in a thousand babies) is taken at a high cost, one that may represent lost opportunities (e.g., that of reducing other risks) over the longer term.

To trade a technological fix of an immediate problem for a solution that possibly has negative long-term consequences is perhaps an inherent danger of technological progress. In particular, technologies that deal with the extraction of natural resources or the disposal of wastes can be seen to move environmental impacts in a three-dimensional space—geography, probability, time—away from local, certain, imminent impacts towards geographically remote (or undefined), uncertain (but possibly very large) problems occurring in the distant future (Sterner, 2005). In a similar way, Holdren and Smith (2000) saw the development of environmental protection as a shift on a space-time plane: from indoor air pollution to local to regional to global air pollution, and at the same time from pollution with immediate consequences to pollution with delayed impacts. Holdren and Smith's third dimension, closely related to the spatial dimension, is the shift from health impacts to ecological impacts. But not all technological fixes are necessarily Faustian Bargains. The original Faustian Bargain demands continued striving in return for present reward.

The large and finally insurmountable challenge of technology assessment is to compare the known problems a technology solves with the unknown problems it creates. To conclude from this that technology assessment is futile and that we should always choose to go ahead with what technological ingenuity offers would be as misguided as refusing any technological progress because of its unknown consequences. The Faustian drive dominates Western society, but we cannot survive without some of the wisdom of Philemon and Baucis.

4. CO_2 capture and storage

CO_2 capture and storage is a Faustian Bargain par excellence. Both views of the Faustian Bargain can be seen in this proposed technological fix: the devil's view, expecting to lead Faust into temptation; and Faust's (and God's) view, knowing that he will never give up his vigilance.

The temptation that CCS offers is the extension of the fossil-fuel era by perhaps a few 100 years. It is a technology designed to limit emissions of CO_2 to the atmosphere, but it extends the period during which CO_2 is emitted. It is a double-edged sword. Research on CCS and talk about the promise of a technology that can fix the CO_2 problem can easily delay more durable measures (Hawkins, 2003). CCS may be, politically, an easy way out of having to make more difficult and sustainable choices. It could divert resources from the search for increases in energy efficiency or investment in non-fossil energy sources. CCS could provide temporary relief, but it may also make the whole of humankind more dependent on fossil fuels, and thus make a change-over later more difficult. Mitigation technologies can be pursued in parallel, and Faust's original bargain was to continue the striving. The short-term interest of the fossil-fuel industry is to accept the devil's assistance and to extend the era of fossil fuels. This is not to imply that other approaches to confronting climate change are without cost or risk, it is to make clear that a Faustian Bargain comes with both commitments and an uncertain outcome.

The other side of the Faustian Bargain is the commitment to long-term vigilance, in managing the captured CO_2. Two classes of risk must be considered for every storage site: sudden and gradual (Socolow, 2005). For acceptable storage, sudden leakage must be very unlikely and gradual leakage must be very slow. Sudden leakage could endanger people, and gradual leakage would endanger the climate system.

Geological storage of CO_2 is most likely to occur at depths of at least 800 m, where CO_2 exists in a 'supercritical phase' that is nearly as dense as the brine it displaces.

[1]NSAIDs are Non Steroidal Anti-Inflammatory Drugs.

A large wealth of experience suggests that fluids like CO_2, which are less dense than water, can be stored safely (IPCC, 2005), (Benson et al., 2003). For example, over 450 projects in 35 US states now store natural gas to meet fluctuating needs locally.

The risk and consequences of leakage depend, of course, on how much CO_2 is eventually stored. This quantity could become very large. Emissions from fossil-fuel use totaled 24,400 million tonnes of CO_2 in 2000, and there are now nearly 8000 industrial sources with annual emissions of more than 0.1 million tonnes of CO_2 that might be considered for CCS projects (IPCC, 2005). The worldwide storage capacity may be 2000–2,000,000 million tonnes of CO_2 (IPCC, 2005). In a Special Report, the IPCC suggested that for well-selected, designed, and managed sites, the fraction of CO_2 retained in storage sites is 'very likely' to exceed 99% over 100 years, but they acknowledge that 'site monitoring may be required for very long periods' (Summary for Policy Makers, p. 13). (If leakage is detected, there are some remediation techniques available to stop or control it.) But the challenge of detecting and addressing leaks is a large one. The International Atomic Energy Agency's task with respect to nuclear waste, by comparison, is difficult but feasible on account of the ease with which small amounts of radioactivity can be detected. Long-term liability issues associated with CO_2 leakage have not been resolved. Who will accept this Faustian commitment?

5. Conclusion

CSS appears to be a classic Faustian Bargain. But, as in Faust's initial bargain, it need not mean that our soul is left to the devil. It should mean that we accept the challenge of continual striving and vigilance, striving for more durable answers to global climate change and vigilance in assuring that stored carbon is not subsequently released to the climate system.

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