Workbook for
Ethics and Engineering

Applied Physics
Chemical Engineering
Biochemical Engineering
Life Science & Technology
Materials Science and Engineering

WM0320TN; WM0329TU

Edition: September 2009

Edited by dr D. Koepsell and ir B. Taebi

Several chapters that will not be used in the class have been omitted from the September 2007 edition. Chapter 1, 3, 4 and 6 have been revised and Chapters 2 and 7 concern two new added chapters with assignments on the topics of normative ethics and sustainability.

Edition: September 2007.
Edited by dr H. Zandvoort, ir G.J. van Hasselt and ir B. Taebi

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Edited by dr H. Zandvoort, dr J.A.B.A.F. Bonnet and ir G.J. van Hasselt with the assistance of dr J.J. Kole.

This Workbook is a merger of the Workbook "Ethics and Life Science and Technology Ethics and (Bio)Chemical Engineering" (code wm0329st), edition January 2005, and the Workbook Ethics for Applied Physics (code: wm0320tn). The text of these two preceding workbooks has been modified at several places. As a consequence, these preceding workbooks can no longer be used in the courses wm0320tn and wm0329st.

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Preface

This Workbook, together with the Reader *Ethics and Engineering,* contains the teaching material for the ethics course for the MSc programmes Applied Physics, Materials Science and Engineering and for the MSc programmes Biochemical Engineering, Chemical Engineering, and Life Science & Technology. Whereas the Reader looks at ethical issues in engineering and technology from a general and theoretical perspective, the Workbook provides specific examples, cases, questions for discussion, and exercises. The Workbook provides the material for the Working group-part of the course. For all information regarding the set-up and organisation of the course we refer to the relevant pages on Blackboard.

Students attending working group sessions will have conferred with their tutors before each session to devise a schedule and plan for each working group meeting. Typically, two students divide the duty of chairing a half of each session. So, student A will chair the first 45 minutes, and Student B will chair the second. The chair shall have devised a brief presentation, summing up the reading and leading the discussion of the reader and workbook materials for his or her term as chair. The chair should provoke discussion, stimulate participation, and prepare fully for his or her session. Each chair for each session might, following a summation and discussion of questions also devise an exercise based upon the materials, including an impromptu debate, supplemental role play, slide-show presentation, or similar excercies applying the materials to a real-world or hypothetical case. Be imaginative.

Before the first meeting, tutors will have selected chairs for the first meeting, after which students and tutors may develop a schedule for all following sessions for the quarter.

Attendence at the working groups is mandatory, and the final meeting will involve brief presentations by all students. This workbook should provide the framework for the tutorials, but students and tutors are encouraged to bring in external materials, issues, and questions as time and interest allows.

1. Scientific fraud and codes of conduct

1.1. Introduction

In scientific communities *peer review* is a commonly accepted procedure for reflecting on scholarly articles. The general idea is that scholars review each other's work. Normally the author and the reviewer do not know each other; the rationale behind this *double blind peer review* is that one should judge a scientific work on its merits; in such evaluation author's name is assumed to be irrelevant.

In the following articles you will read an example of a case in which the peer reviews procedure seems to have failed. In the autumn of 2002 it emerged that Jan Hendrik Schön, then working for the prestigious Bell Labs, had simply made up a large part of the research results that he had been publishing at high speed in top periodicals. Schön was immediately dismissed after the Beasly committee made its judgment public (the Beasly report, which accuses Schön of scientific misconduct, can be found on Blackboard).

Codes of ethics of two professional engineering organisations are further included in this chapter. You don't need to read them carefully, but we've included them though for two reasons: i.e. 1) for you to get acquainted with two important codes of conducts that you might come across later on and 2) to see whether these codes could provide any guideline in addressing the issue of peer review for engineering sciences that also need to deal with many experimental results.

Included codes of conduct are:

- The code of the KIVI-NIRIA, Koninklijk Instituut voor Ingenieurs. At the moment this code is only available in Dutch (also downloadable at: www.ingenieurs.net). Because of its importance in the Dutch context, we offer here our own (unauthorised) translation.
- NSPE Code of Ethics for Engineers (National Society of Professional Engineers) (see also: http://www.nspe.org/ethics/home.asp)

1.2. Questions

1. Do you find it odd that peer review procedures have not revealed Schön's results as fictive? If so, what could have caused this not to happen? If not, do you think that nonetheless it should have been discovered at this stage, and can you think of ways to improve peer review procedures to this end?
2. Is the peer review mechanism to be considered problematic? If so, do you see possibilities other than peer review to prevent this kind of failure?
3. Do you find it right that the co-authors of these papers have not been accused of fraud? How far would you say that the responsibility of co-authors to check research results extends?
4. Do you think that any of the two professional codes could provide a guideline for 'peers' who are invited to review articles in engineering sciences? Can you suggest any alterations to make them more appropriate for dealing with peer review examples?
5. Should the expenses of research that is aimed at reproducing the results that turn out to be made up by other researchers be reimbursed? Why (not)? Who should reimburse these expenses?

1.3. "In the matter of J Hendrik Schön"

physicsweb.org, November 2002
By David Goodstein

Bell Labs' decision to fire Jan Hendrik Schön for faking data shows that physics is vulnerable to scientific misconduct when the wrong factors line up. David Goodstein argues that the physics community must continue to root out misconduct wherever it appears.

"The physicists have known sin," J Robert Oppenheimer is famously said to have remarked on the occasion of the first nuclear explosion. Sin in the form of faking scientific data seemed to be restricted to biology and related sciences, not physics. I used to think I understood why.
"There are three danger factors in scientific misconduct," I would lecture to my classes in research ethics and anyone else who would listen. Not that misconduct in research happens whenever these factors are present. They are often present and misconduct in science is very rare. But these factors were present in every case I've studied.

The first factor that can trigger misconduct is that the scientist is under career pressure. That's not much of a discriminator, because all scientists are under career pressure all the time, but it does point up the fact that this kind of misconduct is not motivated by simple monetary gain.

Second, the perpetrators always think they know the right answer. In other words, faking data is never done with the intention of inserting a falsehood into the body of scientific knowledge. The intent is always to insert a truth without bothering to go to the trouble of doing the experiment properly. This kind of misconduct is always a violation of the scientific method, never purposely a violation of scientific truth.

Finally, the work is always in a field where reproducibility is not expected to be very precise. For example, if you take two organisms that are as nearly identical as you can make them - say, two transgenic mice - and expose them to the same carcinogenic agent, you don't expect them to develop the same tumour at the same time in the same place. So biologists who might be inclined to cheat generally don't have to fear that someone will quickly prove them wrong by repeating the experiment. That, I would conclude, is why faking data occurs in biology, not physics. Misconduct exposed Now two high-profile cases of cheating in physics have suddenly surfaced. One involves the announcement and later retraction of the discovery of elements 116 and 118 at the Lawrence Berkeley National Laboratory (LBNL). The other involves a young researcher at Bell Labs named Jan Hendrik Schön. These cases promise to pose a severe test for my theory.

Unfortunately, as in many cases of scientific misconduct, little is known to the outside world about the LBNL case. An investigation took place, and a physicist, Victor Ninov, was fired as a result (*Physics World* August p7, p13). But, at the time of writing, the report of the investigation has not been made public.
Quite the opposite is true in the Schön case (*Physics World* June p5, p15). In a rare instance of openness in the murky field of scientific misconduct, the management of Bell Labs made it clear from the outset that it intended to make the results of its investigation public. It has now done so.

The general outlines of the case have been widely reported. Schön seemed to be a brilliant young condensed-matter experimentalist heading straight for a Nobel prize. His field was organic or carbon-based semiconductors, and Schön appeared able to grab every holy grail in the business.

Many of the samples were fabricated at Bell Labs, but they were rendered into devices and the measurements were made at the University of Konstanz in Germany while Schön was waiting for a visa to join Bell Labs. He managed, for example, to use field-effect doping - the use of very large electric fields to change the electron concentration in his samples - to induce such remarkable phenomena as superconductivity and the quantum Hall effect. Other researchers had been unable to reach high enough fields to detect these miraculous effects because of electrical breakdown in the insulating layers that are essential for such experiments. But Schön, using a humble apparatus in Konstanz, had managed to produce aluminium-oxide films of unprecedented resistance to breakdown.

In the period from 1998 to the summer of 2001, he produced research papers at an average of one every eight days, together with a total of 20 collaborators - the most prominent of whom were Bertram Batlogg and Christian Kloc. A blazing superstar of physics had been launched (see "Organic research goes into overdrive" *Physics World* January 2001 p9).

Then the wheels started to come off. Late last year Schön announced that he and his collaborators had produced a single-molecule transistor - the logical end point of Moore's law, which, crudely, says that the number of transistors that can be crammed onto a computer chip grows exponentially. The news triggered the beginning of an unsuspension of disbelief. Anomalies were pointed out. The data were too perfect, different experiments had identical noise, and so on. This May, Bell Labs appointed a committee, chaired by Malcolm Beasley of Stanford University, to investigate. The committee's report was released to the public, as promised, on 25 September.

The report detailed some 24 specific allegations that the committee had investigated, and found that scientific misconduct by Schön had occurred in at least 16 of them. Schön had done all of his experiments alone, he kept no laboratory notebooks, all his raw data files had been erased from his computer, and all of his original samples had been destroyed or discarded. With only the slightest of misgivings, the report exonerated all of Schön's collaborators. Schön was immediately fired by Bell Labs. Lessons to be learned The case raises a number of issues. Firstly, I find it amazing that, when it arose, Bell Labs had no formal policy on how to handle cases of research misconduct. All US universities that accept federal research funds are required to have such policies, but Bell Labs, which is owned by Lucent Technologies, does not receive federal funds. The attitude there seems to have been one that was common in universities a couple of decades ago: it couldn't happen here, so why do we need such a policy?

The Beasley committee resolved this dilemma by choosing to follow the federal policy that guides the universities. That, for example, established the level of proof of guilt required. Not, as in a criminal case, beyond a reasonable doubt, but rather that a preponderance of the evidence would be sufficient. I imagine that Bell Labs and other industrial laboratories will now get the message and put appropriate policies in place.

A more difficult issue concerns the responsibility of the other authors. The report defines this as an issue not of scientific misconduct but of professional responsibility. It goes on to say that "no clear, widely accepted standards of behaviour exist", because it is an issue that "the scientific community has not considered carefully". In fact the issue here is trust among scientists. Collaborations take place precisely because different scientists bring different skills to the table. If we are responsible for looking over the shoulders of our collaborators, collaborations will fall apart, and much damage will be done to science. Still, it makes one uneasy that there were so many collaborators who never suspected wrongdoing.

What about my theory - those three danger factors I wrote about? In this case they seem to hold up pretty well. Was Schön under career pressure? You bet he was, as is everyone at a place like Bell Labs - or my own institute for that matter. Perhaps that pressure was made all the more severe by the intensely competitive nature of the field he was in, and the unyielding pressure to stay ahead of the curve on Moore's law.

Did he believe he knew the right answer? He still does. In a response attached to the Beasley report, Schön admits mistakes, but writes: "I have observed experimentally the various physical effects...such as the quantum Hall effect [and] superconductivity in various materials...I believe that these results will be reproduced in the future."

Finally, is it a field in which results are not easily reproduced? Yes. Results in this field are notoriously sample-specific. That is, they depend crucially on the skill and luck of the person who prepares the sample. Failure to reproduce any given result in any given sample is not considered proof of anything. Nobody could prove that Schön had cheated just by demonstrating that a given result he had reported does not show up in a particular sample. So my theory survives to be disproved another day. Catching the cheats The Schön case has put scientific misconduct back on the front pages of the newspapers, and this time it is physics that is in the firing line. Inevitably, there will be much debate and soul-searching about what to do. Whatever we decide, we must remember this. Science is a marketplace of ideas, where good ideas must be proven wrong in order to be replaced by better ones. Being wrong, then, is an essential part of progress in science. To the public, it is easy to confuse being wrong with being guilty. We cannot allow that to happen. If scientists start to fear being accused of misconduct when they are wrong, enormous damage will be done to the enterprise of science.

In this case, the system worked. Science is self-correcting, as it is supposed to be. But we must not be complacent. If this kind of misconduct were to become commonplace, science would cease to be self-correcting and would be no better than any other belief system. Rooting out scientific misconduct in a sensible way will always be a grave responsibility for all of us.

David Goodstein is vice-provost and professor of physics and applied physics at the California Institute of Technology

1.3.1.

1.4. "Fraud in the physical sciences"

Science & Technology, Vol.80, No.44, pp.31-33, 2002
By Mitch Jacoby

New cases of data falsification revive old issues in research ethics

Ugly and embarrassing, cases of research fraud crop up now and again. Stories of scientific misconduct wander through academic circles, make their way into journal editorials, and end up on the pages of major newspapers and magazines – giving science a black eye.

The more infamous and talked-about scandals of the past were centred in biological and medical research, leading some physical scientists to believe that their disciplines were relatively safe from data falsification. But two episodes of physics research fraud in the recent past shattered that security. In both cases, one at Lawrence Berkeley National Laboratory (LBNL) and the other at Lucent Technology's Bell Labs, scientific review boards concluded that a researcher committed scientific misconduct and the scientist was fired. But the firings hardly close the cases. Left wide open are questions about the responsibility of research-paper coauthors, scientific institutions, and journals. And although the players are new, the issues aren't. Yet despite the familiar ring to research ethics questions, the scientific community still hasn't quite figured out the answers.

In June 1999, heavy-element researchers at LBNL issued a press release claiming that they had synthesized and detected a few atoms of elements 118 and 116 – elements that had never before been seen. Two months later, the results were published in *Physical Review Letters*.

In heavy-element synthesis experiments, nuclear reactions are carried out by accelerating ions to tremendous speeds and smashing them into targets to form fused nuclei. Researchers look for the telltale signs of successful nuclear fusion reactions by studying the nuclear events that follow the high-energy collisions. In the LBNL study, a ^{208}Pb target was bombarded by an intense beam of ^{86}Kr ions. The researchers reported that, within the enormous data set generated in such experiments, they had detected three sets of a-particle decays that signalled creation and subsequent decay of the new elements.

But after follow-up experiments at LBNL and heavy-element facilities in Japan and Germany failed to confirm the 1999 results, the Berkeley team scrutinized its data and found that the sequence of events that was presented as evidence for creation of element 118 didn't exist in the original data tapes. The group retracted its claim in 2001. Earlier this year, following various reviews and investigations, nuclear scientist Victor Ninov, the first author of the *Physical Review Letters* paper, was fired. According to LBNL Director Charles V. Shank, the retraction was "a result of fabricated research data and scientific misconduct by one individual" (C&EN, July 22, page 12).

But Ninov's problems didn't end there. At about the same time that Ninov was fired from LBNL, Sigurd Hofmann, a group leader at the Institute for Heavy Ion Research (GSI), Darmstadt, Germany, pointed the finger at Ninov. GSI had discovered inconsistencies while reanalysing data from experiments on elements 110 and 112 that Ninov conducted there in 1994 and 1996. Ultimately, the GSI team validated all of its claims for the new elements. Yet two of the decay chains that were published in support of the team's findings, Hofmann told C&EN, were "faked and did not exist in the original data files."

In many ways, the Bell Labs case is similar. In that episode, researchers studying the physics of solid-state electronic devices published a string of papers in the past two years in *Science, Nature,* and *Applied Physics Letters* claiming that organic semiconductors had been fashioned into working field-effect transistors (FETs) and other electronic devices. The group also claimed to have observed superconducting behaviour in fullerenes. The studies, which were widely reported in the press (C&EN included), generated a great deal of excitement in the device physics community and helped strengthen the emerging field of molecular electronics.

But as with the LBNL case, the results couldn't be reproduced. And so researchers in a number of laboratories who were closely studying the Bell Labs papers grew suspicious when they noticed identical-looking signal shapes and noise levels – blip for blip – in data curves that reportedly described nonidentical systems. For example, current-voltage plots from a pair of devices that were supposedly made from negative- and positive-charge-carrying FETs were nearly indistinguishable.

In May, the scientists who discovered the questionable results notified Bell Labs management, the relevant journals, and others. Bell Labs responded by appointing a review panel of five outside scientists, headed by Malcolm R. Beasley, professor of applied physics and electrical engineering at Stanford University (C&EN, May 27, page 17). In September, the committee announced its findings: Jan Hendrik Schön, the corresponding author of most of the 25 papers about which allegations were made, committed 16 instances of scientific misconduct, including various forms of data substitution and fabrication. Schön was promptly fired.

In both cases, the review panels found that a single scientist acted alone in falsifying data and cleared all coauthors of scientific wrongdoing. In Ninov's case, that meant that 14 coauthors on the element 118 paper were officially off the hook. Likewise, the 20 or so scientists with whom Schön collaborated over the years were cleared.

But the idea of clearing all authors does not sit well with everyone – not even with the committees that cleared them. The panel that reviewed Schön's case asks whether the coauthors exercised "appropriate professional responsibility" in ensuring the validity of the data, noting that by virtue of their coauthorship, "they implicitly endorse the validity of the work."

It's clear that the panel wrestled with the issue of coauthor responsibility. "The committee found this to be an extremely difficult issue, which the scientific community has not considered carefully," it notes in its report. Beasley and the other panel members add that they do not endorse the view that each coauthor is responsible for the entirety of a collaborative endeavour. And they're not alone in taking that position.

For example, Hofmann, who is a coauthor of Ninov's on the GSI papers, tells C&EN that it has been his practice to include senior engineers and others who are responsible for maintaining laboratory instruments, power supplies, and electronics as research paper coauthors. And University of California, Berkeley, chemistry professor Darleane C. Hoffman, an LBNL scientist and coauthor of the retracted element 118 paper, notes that she, too, has made a practice of recognizing the contributions of important support personnel by including their names on papers.
The electronics engineer, for example, plays an important role in ensuring success in an experiment. But, Sigurd Hofmann stresses, the engineer is not involved with data analysis and therefore can't be held accountable for data fabrication committed by a senior scientist. Couldn't the same be said of a group of chemists whose involvement in a project is basically limited to preparing thin-foil targets for bombardment in heavy-element experiments or synthesizing specimens to be wired into electronics devices?

The single crystals of organic semiconductors, thin films, and other materials described in Schön's papers were prepared by Bell Labs chemists – Zhenan Bao in some cases and Christian Kloc in others. Accordingly, their names appear on various papers. "As a coauthor, I take full responsibility for the aspects of the work I have contributed toward the papers," Bao tells C&EN. "In general, I think a coauthor, to the best of his or her ability, should ensure that coworkers carry out their parts of the work correctly and carefully. But we are not experts at everything."

And that's essentially the view of the Bell Labs committee. In their report, Beasley and panel members note that the field of electronic measurements in which data were falsified is outside of the specific areas of Kloc's and Bao's expertise. How could they be expected to notice "misrepresentations" that went unnoticed for so long by experts in the field, they ask?

But while many scientists adopt a similar forgiving attitude about some coauthors, others who are close to the case are less willing to excuse Bertram Batlogg, the physicist who – until he left Bell Labs for a position at the Swiss Federal Institute of Technology in Zurich – was Schön's boss. A number of researchers, including Harvard University chemistry professor Charles M. Lieber, who was one of the first to notice duplicated data curves, ask how a recognized physics authority such as Batlogg, who continued to take credit as coauthor of papers published after he left Bell Labs, could be excused along with less senior scientists. Others wonder why Batlogg didn't grow suspicious and question Schön's remarkable publication rate at a time when sceptics' murmurs could be heard in solid-state physics circles.

Here, too, the Bell Labs panel struggled. "Should Batlogg have insisted on an exceptional degree of validation of the data in anticipation of the scrutiny that a senior scientist knows such extraordinary results will surely receive?" And furthermore, should he have "crossed the line of trust and questioned the integrity of the data?" Ultimately, the panel judged itself unqualified to answer the questions.

But the issue of trust goes to the very heart of the matter. Originally, Ninov was highly regarded at GSI and at LBNL, and so, according to Sigurd Hofmann, falsification was not the type of data issue with which his coworkers were concerned. Instead, they focused on verifying that the data were physically meaningful. And despite scepticism about Schön's track record in the minds of some scientists, others were so impressed that they thought he was on track for winning a Nobel Prize in Physics.

Perhaps trust interferes with objectivity in the peer-review process. Presented with a manuscript from leading experts, referees are more likely to focus on the soundness of scientific arguments and conclusions laid out in a paper than to question the integrity of its authors and their data. But some observers charge that the problem of publishing phony data lies with journal editors who may usher papers through a fast and friendly review process in order to maintain their journal's prestige by publishing high-profile papers. "We at *Nature* unequivocally reject such charges," the journal counters in a recent editorial. And editors at *Science* note that devious scientists will always figure out ways to beat the peer-review process.

That thought resonates with scientists who were duped by a coauthor. Darleane Hoffman insists that original data files should be backed up immediately and researchers should be required to follow proper record-keeping – neither of which happened in the Ninov or Schön cases. "But that won't prevent a really clever person from committing research fraud," she says.

Theodore J. Sheskin, a professor of industrial engineering at Cleveland State University, proposes that, before a paper is released for publication, department heads should examine raw data, observe a demonstration of the reported experiment, and verify that the manuscript has cleared an internal review – as is done at some national labs. In fact, according to LBNL's formal report, the *Physical Review Letters* manuscript did undergo an internal review, but the accelerator wasn't fired up again to give demonstrations.

Maybe the bottom line is "seeing is believing." Both cases of fraud were uncovered because experimental results could not be reproduced, which Darleane Hoffman notes can be viewed as "a triumph of the scientific method." And although data were faked in these cases, Sigurd Hofmann remarks, that does not preclude the possibility of observing the results honestly in the future. "Time will tell," he says.

1.5. Professional code of the KIVI-NIRIA [unauthorised translation]

INTRODUCTION

Engineers have specific knowledge of technology. This implies a (moral) responsibility for development and application of technology, systems and products throughout society.

The KIVI has, therefore, developed a code of conduct for its members. It describes the responsibilities and values of the institute. The code serves the engineer's interest.
The members are expected to act according to this code. It provides a minimum standard for professional activities and individual performance.

THE PURPOSE OF THE CODE IS:

- To provide clarity and insight into the professional position and attitude of the engineer, both in society and the direct work environment;
- To facilitate the personal responsibility of the engineer for delivering thorough work;
- To explicate the responsibilities of the engineering job;
- To form a basis for judgement on (ethical) conflicts in and around the engineering job;
- To provide handles for the interaction between KIVI members (engineers and colleagues)
- To offer the members a discerning capability

THOROUGH WORK

The KIVI presupposes the following values associated with thorough work:

- Care(fullness)
- Expertise
- Integrity
- Objectivity
- Loyalty

The engineer is expected to actively gain insight in the social consequences of his work.

INTENTION AND APPLICABILITY

- The professional code of conduct addresses the members of the KIVI
- The KIVI applauds recognition and/or application of this code outside of its institute

- Third parties cannot derive any rights from this code;
- Externally, the code is intended to be an obligation for diligent effort in good conscience
- A member realises that breaking the rules may lead to his being removed from the institute.

LEGAL

A judge may refer to the code when assessing the legal position of an engineer. Liability could become an issue in case of "deliberate (wrongful) action" on the engineer's part (this is also often the case even without a professional code of conduct)

CONFIDANT

When KIVI members see themselves facing a dilemma, the institute offers to provide (by making available a confidant through the internal "counselorsystem") an objective opinion based on the code. Members can submit a written request to:
KIVI, f.a.o. Directiesecretariaat, Postbus30424, 2500 GK Den Haag)

RULES OF CONDUCT

1. *General*

Engineers:

1.1 carry out their activities in accordance with legal regulations and written rules and norms;
1.2 act according to the values of thorough work en provide clarity concerning uncertainties and risks associated with their activities;
1.3 guard the safety, health and welfare of all those involved in the realisation of the work and bear in mind the corresponding interests of the users of the work;
1.4 in case of conflict of interest, need to make a choice and report it to the parties concerned, without revealing details;
1.5 dispose of the knowledge and capabilities as deemed required for competent execution of their profession.

2. *With regards to society*

Engineers:

2.1 take into consideration the social consequences of their work and act accordingly;
2.2 share responsibility for the quality of the environment;
2.3 bear in mind better options that are expected to become available during the realisation of work with a long term effect on society and/or the environment;
2.4 bear in mind the cultural values of the country where they work;
2.5 ensure adequate descriptions of the delivered products and systems;
2.6 participate in information of the public at large

3. *With regards to the client and/or the employer*

Engineers:

3.1 are answerable for thorough work;
3.2 only accept work that falls within the bounds of their competencies, and under circumstances that they can control;
3.3 look after the interests of the client and/or their employer in a loyal manner;
3.4 respect confidentiality;
3.5 provide for procedures to enhance the quality of their work;
3.6 report assessable, possible side-effects and risks that may result from their work;

3.7 in their reporting, draw attention to possible consequences of not following up their recommendations;
3.8 demand a compensation for their services that befits the assignment.

4. With regards to co-workers
Engineers in a managerial role:
4.1 facilitate co-workers in personnel matters and provide clarity on task and labour conditions;
4.2 ensure proper education of co-workers;
4.3 adopt an attitude as people manager;
4.4 point out to the co-workers (the need) to act in accordance with the legal regulations and the written rules and norms;
4.5 draw the co-workers' attention to behaviour that raises moral objections.

5. With regards to fellow engineers and colleagues
Engineers:
5.1 adopt a fraternal attitude and are receptive to critical dialogue;
5.2 contribute, where possible, to the development of their profession;
5.3 contribute to the transfer and sharing of knowledge;
5.4 keep abreast of the developments in their profession (field of expertise);
5.5 acknowledge and mention the valuable contributions of their professional colleagues;
5.6 stimulate behaviour in accordance with this code.

1.6. NSPE Code of Ethics for Engineers

Preamble
Engineering is an important and learned profession. As members of this profession, engineers are expected to exhibit the highest standards of honesty and integrity. Engineering has a direct and vital impact on the quality of life for all people. Accordingly, the services provided by engineers require honesty, impartiality, fairness, and equity, and must be dedicated to the protection of the public health, safety, and welfare. Engineers must perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct.

I. Fundamental Canons

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

II. Rules of Practice

1. Engineers shall hold paramount the safety, health, and welfare of the public.

   a. If engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate.

b. Engineers shall approve only those engineering documents that are in conformity with applicable standards.

c. Engineers shall not reveal facts, data, or information without the prior consent of the client or employer except as authorized or required by law or this Code.

d. Engineers shall not permit the use of their name or associate in business ventures with any person or firm that they believe is engaged in fraudulent or dishonest enterprise.

e. Engineers shall not aid or abet the unlawful practice of engineering by a person or firm.

f. Engineers having knowledge of any alleged violation of this Code shall report thereon to appropriate professional bodies and, when relevant, also to public authorities, and cooperate with the proper authorities in furnishing such information or assistance as may be required.

2. Engineers shall perform services only in the areas of their competence.

   a. Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved.

   b. Engineers shall not affix their signatures to any plans or documents dealing with subject matter in which they lack competence, nor to any plan or document not prepared under their direction and control.

   c. Engineers may accept assignments and assume responsibility for coordination of an entire project and sign and seal the engineering documents for the entire project, provided that each technical segment is signed and sealed only by the qualified engineers who prepared the segment.

3. Engineers shall issue public statements only in an objective and truthful manner.

   a. Engineers shall be objective and truthful in professional reports, statements, or testimony. They shall include all relevant and pertinent information in such reports, statements, or testimony, which should bear the date indicating when it was current.

   b. Engineers may express publicly technical opinions that are founded upon knowledge of the facts and competence in the subject matter.

   c. Engineers shall issue no statements, criticisms, or arguments on technical matters that are inspired or paid for by interested parties, unless they have prefaced their comments by explicitly identifying the interested parties on whose behalf they are speaking, and by revealing the existence of any interest the engineers may have in the matters.

4. Engineers shall act for each employer or client as faithful agents or trustees.

a. Engineers shall disclose all known or potential conflicts of interest that could influence or appear to influence their judgment or the quality of their services.

b. Engineers shall not accept compensation, financial or otherwise, from more than one party for services on the same project, or for services pertaining to the same project, unless the circumstances are fully disclosed and agreed to by all interested parties.

c. Engineers shall not solicit or accept financial or other valuable consideration, directly or indirectly, from outside agents in connection with the work for which they are responsible.

d. Engineers in public service as members, advisors, or employees of a governmental or quasi-governmental body or department shall not participate in decisions with respect to services solicited or provided by them or their organizations in private or public engineering practice.

e. Engineers shall not solicit or accept a contract from a governmental body on which a principal or officer of their organization serves as a member.

5. Engineers shall avoid deceptive acts.

a. Engineers shall not falsify their qualifications or permit misrepresentation of their or their associates' qualifications. They shall not misrepresent or exaggerate their responsibility in or for the subject matter of prior assignments. Brochures or other presentations incident to the solicitation of employment shall not misrepresent pertinent facts concerning employers, employees, associates, joint venturers, or past accomplishments.

b. Engineers shall not offer, give, solicit, or receive, either directly or indirectly, any contribution to influence the award of a contract by public authority, or which may be reasonably construed by the public as having the effect or intent of influencing the awarding of a contract. They shall not offer any gift or other valuable consideration in order to secure work. They shall not pay a commission, percentage, or brokerage fee in order to secure work, except to a bona fide employee or bona fide established commercial or marketing agencies retained by them.

III. Professional Obligations

1. Engineers shall be guided in all their relations by the highest standards of honesty and integrity.

a. Engineers shall acknowledge their errors and shall not distort or alter the facts.

b. Engineers shall advise their clients or employers when they believe a project will not be successful.

c. Engineers shall not accept outside employment to the detriment of their regular work or interest. Before accepting any outside engineering employment, they will notify their employers.

d. Engineers shall not attempt to attract an engineer from another employer by false or misleading pretenses.

   e. Engineers shall not promote their own interest at the expense of the dignity and integrity of the profession.

2. Engineers shall at all times strive to serve the public interest.

   a. Engineers are encouraged to participate in civic affairs; career guidance for youths; and work for the advancement of the safety, health, and well-being of their community.

   b. Engineers shall not complete, sign, or seal plans and/or specifications that are not in conformity with applicable engineering standards. If the client or employer insists on such unprofessional conduct, they shall notify the proper authorities and withdraw from further service on the project.

   c. Engineers are encouraged to extend public knowledge and appreciation of engineering and its achievements.

   d. Engineers are encouraged to adhere to the principles of sustainable development[1] in order to protect the environment for future generations.

3. Engineers shall avoid all conduct or practice that deceives the public.

   a. Engineers shall avoid the use of statements containing a material misrepresentation of fact or omitting a material fact.

   b. Consistent with the foregoing, engineers may advertise for recruitment of personnel.

   c. Consistent with the foregoing, engineers may prepare articles for the lay or technical press, but such articles shall not imply credit to the author for work performed by others.

4. Engineers shall not disclose, without consent, confidential information concerning the business affairs or technical processes of any present or former client or employer, or public body on which they serve.

   a. Engineers shall not, without the consent of all interested parties, promote or arrange for new employment or practice in connection with a specific project for which the engineer has gained particular and specialized knowledge.

   b. Engineers shall not, without the consent of all interested parties, participate in or represent an adversary interest in connection with a specific project or proceeding in which the engineer has gained particular specialized knowledge on behalf of a former client or employer.

5. Engineers shall not be influenced in their professional duties by conflicting interests.

   a. Engineers shall not accept financial or other considerations, including free engineering designs, from material or equipment suppliers for specifying their product.

   b. Engineers shall not accept commissions or allowances, directly or indirectly, from contractors or other parties dealing with clients or employers of the engineer in connection with work for which the engineer is responsible.

6. Engineers shall not attempt to obtain employment or advancement or professional engagements by untruthfully criticizing other engineers, or by other improper or questionable methods.

    a. Engineers shall not request, propose, or accept a commission on a contingent basis under circumstances in which their judgment may be compromised.

    b. Engineers in salaried positions shall accept part-time engineering work only to the extent consistent with policies of the employer and in accordance with ethical considerations.

    c. Engineers shall not, without consent, use equipment, supplies, laboratory, or office facilities of an employer to carry on outside private practice.

7. Engineers shall not attempt to injure, maliciously or falsely, directly or indirectly, the professional reputation, prospects, practice, or employment of other engineers. Engineers who believe others are guilty of unethical or illegal practice shall present such information to the proper authority for action.

    a. Engineers in private practice shall not review the work of another engineer for the same client, except with the knowledge of such engineer, or unless the connection of such engineer with the work has been terminated.

    b. Engineers in governmental, industrial, or educational employ are entitled to review and evaluate the work of other engineers when so required by their employment duties.

    c. Engineers in sales or industrial employ are entitled to make engineering comparisons of represented products with products of other suppliers.

8. Engineers shall accept personal responsibility for their professional activities, provided, however, that engineers may seek indemnification for services arising out of their practice for other than gross negligence, where the engineer's interests cannot otherwise be protected.

    a. Engineers shall conform with state registration laws in the practice of engineering.

    b. Engineers shall not use association with a nonengineer, a corporation, or partnership as a "cloak" for unethical acts.

9. Engineers shall give credit for engineering work to those to whom credit is due, and will recognize the proprietary interests of others.

    a. Engineers shall, whenever possible, name the person or persons who may be individually responsible for designs, inventions, writings, or other accomplishments.

    b. Engineers using designs supplied by a client recognize that the designs remain the property of the client and may not be duplicated by the engineer for others without express permission.

    c. Engineers, before undertaking work for others in connection with which the engineer may make improvements, plans, designs, inventions, or other records that may justify copyrights or patents, should enter into a positive agreement regarding ownership.

d. Engineers' designs, data, records, and notes referring exclusively to an employer's work are the employer's property. The employer should indemnify the engineer for use of the information for any purpose other than the original purpose.

e. Engineers shall continue their professional development throughout their careers and should keep current in their specialty fields by engaging in professional practice, participating in continuing education courses, reading in the technical literature, and attending professional meetings and seminars.

Footnote 1 "Sustainable development" is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development.

—As Revised July 2007

By order of the United States District Court for the District of Columbia, former Section 11(c) of the NSPE Code of Ethics prohibiting competitive bidding, and all policy statements, opinions, rulings or other guidelines interpreting its scope, have been rescinded as unlawfully interfering with the legal right of engineers, protected under the antitrust laws, to provide price information to prospective clients; accordingly, nothing contained in the NSPE Code of Ethics, policy statements, opinions, rulings or other guidelines prohibits the submission of price quotations or competitive bids for engineering services at any time or in any amount.

Statement by NSPE Executive Committee

In order to correct misunderstandings which have been indicated in some instances since the issuance of the Supreme Court decision and the entry of the Final Judgment, it is noted that in its decision of April 25, 1978, the Supreme Court of the United States declared: "The Sherman Act does not require competitive bidding."
It is further noted that as made clear in the Supreme Court decision:

1. Engineers and firms may individually refuse to bid for engineering services.
2. Clients are not required to seek bids for engineering services.
3. Federal, state, and local laws governing procedures to procure engineering services are not affected, and remain in full force and effect.
4. State societies and local chapters are free to actively and aggressively seek legislation for professional selection and negotiation procedures by public agencies.
5. State registration board rules of professional conduct, including rules prohibiting competitive bidding for engineering services, are not affected and remain in full force and effect. State registration boards with authority to adopt rules of professional conduct may adopt rules governing procedures to obtain engineering services.

2. Philosophical Ethics

2.1. Meta-Ethics, Normative Ethics, and Applied Ethics

Ethical theories have been devised for millennia, primarily by philosophers, and typically focusing on issues of "meta-ethics," in other words: trying to find the correct manner by which we can judge right and wrong. Recently, however, ethicists have become frequently concerned with question of applied ethics, particularly pertaining to real moral dillemas that have caused pain and suffering in the world because people acted poorly. While applied ethicists are interested in delving into the question of which moral theories can be supported logically and practically, they also focus on solving real-world problems. Much of modern applied ethics developed first in the field of Medical Ethics, which is more broadly encompassed now by Bioethics. As you'll see from the article below, this was in response to specific historical atrocities and generally recognized failiures of professionals to safeguard the integrity of their professions. Since 1945, applied ethics has branched out to encompass scientific research integrity, business ethics, military ethics, and numerous other fields in which failures to abide by certain standards or principles have resulted in pain, suffering, or death. In all instances, ethics investigates the issue: what is the "good." Meta-ethics is the "science" of judging ethical theories against each other. Normative ethics is the investigation of "how ought we to act" and it encompasses a number of distinct ethical theories. Applied ethics involves taking the lessons of normative and meta-ethics, and applying them to particular contexts for public policy reasons – namely, to achieve certain ends. In this way, applied ethicists bridge the worlds of speculative philosophy, and everyday (often urgent) issues.

2.2. Questions

1. Why are there differing approaches to determining the "good" or the "right," and how does this affect our ability to make judgments or create policies?

2. Think of examples of how differing ethical theories lead to differing results or judgments in ethical dillemas?

    i. can these differences be resolved, or must we choose a particular ethical1 theory and abide by its resolution ?

    ii. if you cannot find such an example, try to explain why you think that differeing ethical theories may lead to similar resolutions to ethical conflicts

3. What ethical theories guide your decisions and actions, and why? You may never have thought about it before, but try to justify your beliefs about the proper" approach to the "good" with argument. Not everyone takes the same approach. Does this cause real-world issues and conflict in both particular instances and in policy? Give some examples.

4. In the reading below, the author takes a hybrid approach to a certain type of ethical dilemma. First explain the dilemma (a conflict between two apparent duties and responses) and then explain why the approach in this article can be called a "hybrid."

5. Do all professionals have equivalent duties? From where do their duties come, if they have them, or if not, then why not?

6. Do scientists' and engineers' ethical considerations differ from those of lawyers and doctors? Why did doctors and lawyers develop methods not only for teaching and policing ethics in their professions long before scientists and engineers? Was there a historical reason?

7. How do evolving technologies and approaches to technological problems challenge ancient notions of ethics? Are there modern moral dillemas posed by new technologies for which no one ethical approach may be satisfactory? What might this imply about the nature of ethics as a field of study versus ethics as an applied field?
8. Which ethical theories are incorporated into the Belmont Principles? How might they be relevant to other professions, and what might they lack?

2.3. On Genies and Bottles: Scientists' Moral Responsibility and Dangerous Technology R&D (forthcoming in Science and Engineering Ethics)

"On Genies and Bottles: Scientists' Moral Responsibility and Dangerous Technology R&D" (forthcoming in *Science and Engineering Ethics* DOI 10.1007/s11948-009-9158-x)

David Koepsell

abstract

The age-old maxim of scientists whose work has resulted in deadly or dangerous technologies is: scientists are not to blame, but rather technologists and politicians must be morally culpable for the uses of science. As new technologies threaten not just populations but species and biospheres, scientists should reassess their moral culpability when researching fields whose impact may be catastrophic. Looking at real-world examples such as smallpox research and the Australian "mousepox trick", and considering fictional or future technologies like Kurt Vonnegut's "ice-nine" from Cat's Cradle, and the "grey goo" scenario in nanotechnology, this paper suggests how ethical principles developed in biomedicine can be adjusted for science in general. An "extended moral horizon" may require looking not just to the effects of research on individual human subjects, but also to effects on humanity as a whole. Moreover, a crude utilitarian calculus can help scientists make moral decisions about which technologies to pursue and disseminate when catastrophes may result. Finally, institutions should be devised to teach these moral principles to scientists, and require moral education for future funding.

Keywords: dangerous technology, moral responsibility, duty of restraint, scientific ethics, research ethics

Introduction

You are a scientist, and your "eureka!" moment comes in your dreams. Hastily, you bolt from bed and jot down some initial formulas. You have conceived of a way to double the yield of a hydrogen bomb. As your euphoria subsides, you begin to ponder the consequences of this breakthrough, and realize its narrow range of use, limited only to offensive thermonuclear weapons. You also realize its discovery by others is eventually inevitable, although perhaps at best 5 years off.
Or perhaps you're a geneticist, and you've figured out that a clever bit of splicing can turn a certain virus into an even more lethal form. The process is scientifically easy to do, aesthetically elegant, and the result terrifying. A plague that might have stuck down one in ten people in its natural form would become deadly to nine out of ten. Moreover, a vaccine would be difficult to develop. You ponder the implications, and consider whether you should move forward with experiments and eventual publication.

Or finally, you are a nanotech researcher, trying to wed computing with materials. Your dream is to create molecule-sized robots that will do our bidding, constructing items atom-by-atom, capable of user-generated, customized alterations, and fully recyclable. As you near your goal, you realized the full potential of your new creation, which could just as easily disassemble a human being as construct a cup. You consider not only whether and how evil uses of this breakthrough technology might be prevented, but also whether the potential harms outweigh all potential benefits.

These are not merely academic hypotheticals, but rather accounts of actual events and dilemmas, both past and present. This paper will consider some historical events, and the ethical quandaries posed by each to real-world researchers. Usually, when discussing the moral implications of various technologies and sciences, we take for granted certain presuppositions, such as: "we can't put the genie back in the bottle," and that ethics is the realm of technologists, not scientists, since scientists have a duty to explore all questions, but technologists have no duty to release every technology. Is it conceivable that these presuppositions are erroneous? Do scientists have duties, regarding especially dangerous aspects of nature, NOT to pursue certain fields of research? Do they share responsibility with technologists who eventually release dangerous technologies? Does this responsibility involve moral culpability whether or not there are any harms that result?

These questions and assumptions deserve a second look. They were the focus of a number of thinkers, including scientists such as Einstein and Oppenheimer, at the beginning of the nuclear age when scientists who had been involved in the development of nuclear weaponry came to oppose the tools they had helped develop. It's an age-old angst, borne in the Frankenstein tale, involving the inevitable clash of unbounded, unfettered scientific exploration and deadly consequences that sometimes result. Too often, scientists have plodded or lunged along, investigating new means of engineering more destructive technologies, insulated by the concept that science should never be stifled, and that liability for the tools eventually developed because of their investigations rests solely on technologists, engineers, and politicians. But what justifies the disavowal of moral culpability by those in the best position to reveal new and deadly aspects of nature? Is there any moral duty on the part of individual scientists to simply say "no" to investigating those things whose only or best uses are to cause harms?

The Scientific Firewall

It has long been a staple of ethical debate regarding scientific research that science is open and free, and only engineers need worry about the applications to which they put scientific discoveries. The canard goes: science is ethically neutral, and there is in fact an ethical duty to investigate all natural phenomena, so therefore, no scientist need stifle his or her own research. The next step of this argument is to assert that while science ought to be utterly unfettered and free, technologists, engineers, and politicians are both practically responsible and morally culpable for the uses to which any scientific discovery is put. This argument works best with "dual-use" scientific subjects, like bioweapons, nuclear fission, and fusion. [1]. The tremendous possible peaceful uses of thermonuclear technologies argue well for most scientific investigation regarding the underlying sciences. But is this true for all sciences, do they all have "dual-use" features that insulate scientists from moral culpability when doing basic research?

Consider the recent, real-world example of smallpox. By 1977, a world-wide concerted effort led to the successful eradication of smallpox in the natural world. Its only host is humans, and in the years since its successful eradication, no naturally-occurring infection has been documented. This was one of the most successful and heralded scientific and technical enterprises ever. The smallpox virus was virtually extinct, except for some notable stockpiles. The two nations that spearheaded the eradication, coordinated by the World Health Organization (WHO), were the United States and the Soviet Union. Each maintained frozen stockpiles of smallpox samples following the eradication, ostensibly for the purposes of doing scientific research. Then things got out of hand. While WHO and others debated whether the remaining stockpiles ought to be destroyed, some scientists chimed in against the plan. They argued that stockpiles ought to be kept so that further research on smallpox could be done. Some even argued against the eradication of a virus species on moral grounds. The decision to destroy the stockpiles was delayed, and then the stockpiles began to be exploited. There is evidence, including the statements of former Russian president Boris Yeltsin, that during the Cold War, the Soviet Union defied the Biological Weapons treaty and weaponized smallpox, producing it in bulk, and making it more deadly by "heating" it up, essentially making it less vulnerable to existing vaccinations and anti-viral drugs by exposing it to evolve more robust strains. [2] In the process, stores of smallpox apparently left at least one of the two designated repositories, and now the genie is likely once again out of the bottle.

Once again, in 1999, the world's two custodians of the only known stockpiles of smallpox were on the brink of deciding to destroy the stockpiles (inasmuch as they were believed still to solely exist in the hands of Russian and U.S. scientists) when again some scientists chimed in with a chorus of objections. There were also scientists, some of whom had worked on the original Eradication, who argued for the final destruction of smallpox everywhere. In the U.S., President Bill Clinton was convinced by those who favored preserving the stockpiles, and the window has now finally closed. The Centers for Disease Control and others working with the U.S. Dept. of Defense engaged in some controversial studies with smallpox in 2000 and 2001, and successfully created an animal model of the disease, a scientific feat that had hitherto been deemed impossible. This research has since been criticized as being over-hyped, as the animal models that resulted required extravagant forms of exposure before contracting smallpox, making them less-than ideal subjects for experimentation. The research has further been criticized as being unlikely to lead to any useful discoveries, given that smallpox has been eradicated from the environment and only poses a threat from the current custodians of the virus: the U.S. and Russia, who could have eliminated it once and for all, but didn't. [2]

In a similar vein, and related to the decision to revitalize U.S. smallpox research, some Australian scientists made quite a stir when they decided to see what would happen if they did some genetic engineering on the mousepox virus. By tinkering with the virus, inserting a mouse gene into the virus itself, they discovered they could defeat any immunity acquired by mice who had been vaccinated, and created a lethal, vaccine-proof mousepox virus with some simple genetic engineering. When U.S. military researchers got wind of this experiment, reported both at a poster-session at a conference, and in a journal article, the repercussions for potential mischief with the smallpox virus were obvious. [2] There are obvious ethical questions that arise with both the Australian mousepox experiment and the U.S./Russian decision not to destroy the last vestiges of the smallpox virus when the opportunity existed. In each case, to differing extents, one might ask whether the risks of the research justified the potential benefits. Weighing the scientific justification against the potential risks of the research seems inadequate, however, to convey the ethical quandary posed by this and similar research. It is a quandary posed by research and development of other technologies, notably in the 20th Century, and that was partly responsible for the development of modern principles of research ethics. The question one might reasonably ask is: do scientists owe a duty to humanity beyond the relentless, unfettered search for natural laws? The verdict, at least in the realm of bioethics, has been established to be affirmative… there are general ethical duties that outweigh research itself, and that temper behaviors at least when they directly affect human subjects. [3]

The Bioethics Example

It took some terribly visible ethical lapses by Nazi physicians to begin the discussion of codes of ethics governing human subjects research. The Nuremburg Code was instituted because of the Nuremburg trials, and revelations about the use of concentration camp prisoners for experiments, devoid of pain-relief measures, any semblance of consent (much less informed consent), or any shred of human dignity. The Nuremburg Code served as the founding basis for the evolution of bioethical principles throughout the rest of the Twentieth Century. Principles such as the right of subjects to receiving informed consent before being experimented on, and of being treated with dignity rather than used as mere means to ends, derive from well-known and generally accepted philosophical traditions, but were ignored historically by researchers even outside of Nazi Germany. Well-known examples such as the Tuskeegee syphilis study, the Milgram study (both in the U.S.) and others, prompted the development and institutionalization of bioethical principles in both professional codes and federal and state laws. [4].

Simply put, before the "common rule", the Belmont report, and similar codes in European nations specifically applied through laws and regulation the principles enumerated in the Nuremburg Code, human subjects continued to suffer in the name of science. We might speculate as to why scientists would fail to apply commonly-held ethical principles, such as truth-telling, seeking consent, and preventing foreseeable harms, but motivations are ultimately not the issue. The fact is, it took creating institutions intended to oversee human subjects research in order to finally begin to systematically prevent such abuses. It is very likely that many of the scientists over the ages who have mis-used humans subjects in the course of their experiments never intended to cause undue harms,, or justified any harms by the potential for greater rewards from their study. A prime example is the completely un-consented to use of a child by Edward Jenner, the inventor of the smallpox vaccine. Jenner's work involved deliberately trying to infect a child, without adequate controls, animal studies, or consent. Fortunately, his hypothesis turned out to be accurate, and the use of cowpox to vaccinate the child prevented his death. Jenner's work saved countless millions, but his ethics was clearly wanting. Such a study today would not have been possible given that animal trials would be useless without a proper animal model for smallpox. [4]

It is likely that Jenner and other scientists similarly situated never meant specific harm, or at least that they justified the potential for harm to a particular subject by the potential for life-saving new treatments for many. What cases like this illustrate, however, is the fact that science has at times proceeded as though ethical concerns were an after-thought, or even completely tangential to the scientific enterprise. Even after the Nuremburg trials, scientists fell into the trap of weighing more heavily the value of potential benefits to be gained from research over individual duties of upholding dignity, providing informed consent, justice, and beneficence. Now, Institutional Review Boards and Ethics Committees provide oversight where human subjects are used in research, and help to give guidance to scientists who might make similar errors. But not all research involves direct use of human subjects. Rather, some research has only potential, future impact on populations, ecosystems, or even humanity as whole. No regulatory body requires vetting of that sort of research.

The example of the development of bioethical principles and institutions intended to apply them suggests that sometimes, scientists do not self-regulate when it comes to ethical behaviors. It suggests nothing about motivations, however. It seems likely that ethical lapses are generally caused by lack of introspection, rather than malefiscence. This lack of introspection may be exacerbated by the prevailing attitude among philosophers of science and scientists themselves, namely: scientific investigations ought to proceed without limit, and only politicians, technologists, and engineers are to blame for the unethical applications of scientific discoveries through technologies. But as is clear in the example of bioethics, and numerous documented examples of ethical lapses by researchers conducting human subjects experiments, sometime bad things are done in the name of science itself, well before the application phase of a new technology.

There is a vast and growing literature addressing the ethics of so-called "dual-use" scientific research, often in the context of the smallpox example, and other bio-security or bio-weapons agents and research. The frame of this discussion has largely included the perpetuation of the notion that "legitimate" research often has illegitimate uses or consequences. Some have argued from this context that scientists must take upon themselves certain ethical duties and responsibilities, while others have maintained the standard argument that moral culpability lies with those applying the research, not those doing it. [5], [6, [7]. Looking at the development of bioethics as a field, and considering its institutions and principles, one might ask whether the Belmont report needs some updating. With a little tweak, we might well fashion a set of principles just as elegant and concise as those enumerated in the Belmont report, aimed not just at scientists doing research on human subjects, but rather at those whose research impacts humanity as a whole. Let's consider this possibility, see how a modified set of Belmont principles might be applied more generally to all scientific research, and then take up the question of how institutions might then be created that could implement these principles. The discussion is framed with examples, both real-world and hypothetical, and considers also the extent to which some scientific research might never be considered "dual-use."

Respect, Beneficence, and Justice

These three essential principles of biomedical ethics frame all reviews of proposed biomedical research involving human subjects. Although based on long-debated principles of ethics in general, and owing much to standard notions of both utilitarian and deontological ethics theories, the Belmont principles are thoroughly pragmatic, and derived clearly from the most prominent ethical lapses that stoked the report's authorship. They include:

1. Respect for persons
2. Beneficence
3. Justice

The principle of respect for persons is akin to the Kantian notion that people may not use each other as means to ends, but must treat each other with equal dignity -- as ends in themselves. In the Tuskeegee study and other notable lapses of scientific ethics, human subjects were used as means to ends, just as other scientific tools might be, without regard for equal dignity of the subject. The principle of beneficence simply requires that human subjects research be conducted with good intentions. It ought to be pursued not merely for the sake of scientific curiosity, but rather to cure some ill, to correct some harm, or otherwise benefit humanity. Finally, the principle of justice requires that populations or individuals who are vulnerable (like children or historically-mistreated minorities) must be specifically protected in the course of research.

Debate about the merits and application of these principles continues, but they have also become institutionalized in the form of guiding principles used by governmentally-created review bodies that now oversee all human-subjects research in most of the developed world. Despite the philosophical status of debates regarding the Belmont principles, they are in effect already enacted, accepted as part of the background of all human-subjects research, and devised as a hurdle that must be overcome when proposing new experiments involving human subjects. While ethical lapses still occur, as we have seen with such widely-disseminated stories as that of Jessie Gelsinger, we can now gauge the conduct (or misconduct) of researchers involved in these lapses, and educate researchers about how to avoid them in the future. In other contexts, both laws and moral codes do not prevent every harm, but provide contexts for judgments when harms occur. Laws and moral codes still serve to educate, and when agreed upon generally, frame our moral debates over particular acts, intentions, and consequences.

These principles are not unique to the realm of bioethics. They frame many of our everyday acts and intentions, and serve as the basis for both moral and social education and regulation in our everyday lives. Despite their expression and adoption in the realm of "bioethics," what prevents their application to other fields of investigation? Perhaps it is because the sciences outside biomedicine have had fewer public and noteworthy instances where research has caused visible harms. The deaths or injuries of human subjects used in research typically cause public outrage and provoke action. Research which has no such immediate consequence is unlikely to get that sort of notice. But does this mean that the Belmont principles are not more generally applicable? If we believe that these principles have no application outside of biomedical research involving human subjects, then we must justify some moral horizon for intentions and acts of scientists. In other words, we would have to justify ignoring the potential for misuse or harms to those not immediately within the control of the researcher, even where those harms might well outweigh or outnumber harms posed to potential human subjects.

To put this into context, let's consider a fictional technology at the center of Kurt Vonnegut's well-know breakthrough novel, Cat's Cradle. In this novel, a fictional scientist named Felix Hoenikker discovers a permutation of water that is solid at room temperature. He hides his discovery before he dies, but the secret remains in the possession of his children. Ice-nine possesses the ability to turn any body of water solid given that a single molecule of it will "teach" all other molecules next to it to become ice-nine, creating a chain-reaction that freezes any body of water with which it makes contact. It does the same to any water in an organism's body if ingested. The fictional ice-nine is clearly a terrifying scientific discovery. Vonnegut based the character Hoenikker on the Nobel Prize-winning Irving Langmuir, whom Vonnegut knew through his brother's association with Langmuir at General Electric. Of Langmuir, Vonnegut said: "[he] was absolutely indifferent to the uses that might be made of the truths he dug out of the rock and handed out to whomever was around. But any truth he found was beautiful in its own right, and he didn't give a damn who got it next." [8]

In the book, ice-nine inevitably gets released into the environment essentially bringing about the end of the world, all life on it, and all but a handful of people who manage to survive. The research on, and discovery of ice-nine would never have fallen under the purview of bioethical principles as enunciated in the Belmont Report. While ice-nine is fictional, smallpox is not and it poses many of the same questions, real-world threats, and ethical challenges as that posed by Vonnegut's book. Is the beauty and truth of science justification enough to investigate even the deadliest potential technologies or discoveries? Are there ethical principles that bind individual scientists in the absence of regulatory institutions? Can the Belmont principles be extended to scientists doing research only indirectly involving human subjects where the potential effects of an avenue of study impact humanity as a whole?

Extending The Moral Horizon

Most arguments concerning the morality of certain types of basic research focus on issues of dual-use and unintended consequences. These arguments concentrate on the distinction between "legitimate" scientific investigation vs. unethical uses of the research. As discussed above, this presupposes that scientific research is always in a different moral position than the application of that research. What justifies this assumption? Do scientists enjoy a unique position occupied by no other fields or professions? Let's examine some reasons why they might before considering whether scientific inquiry itself, prior to its application through a particular technology, may ever confer moral culpability.

Some might contend that scientific inquiry alone can never confer moral culpability because inquiry is personal, a matter of conscience, and subject to no restrictions at all. Limiting inquiry in one realm might lead us on a slippery slope of censorship, thought-police, and other clearly unsavory interference with free thought. We don't want regulators to prevent scientists from doing legitimate research, looking over shoulders to police scientific investigations, and preventing the acquisition of knowledge about nature. Indeed, governmental interference with scientists' research has provoked the wrath of both scientists and the public, especially when done in the name of particular ideologies [9]. Let's take it as a given that this sort of regulation is tricky at best, Orwellian at worst. But just because we don't want government or regulators overseeing the actions of an individual, doesn't mean that that person's actions or even intentions, are free from moral scrutiny. We often and comfortably make moral judgments about conduct and intentions that have no direct effect on others, even when we don't tolerate or desire any institutional regulation. Yet there are still strong arguments supporting the notion of unfettered scientific inquiry, devoid both of governmental and self-regulation.

Science doesn't kill people; people with technologies kill people. Of course, this is a perversion of the U.S.'s National Rifle Association motto: "guns don't kill people; people kill people." There is some sense to this. Artifacts like crossbows, rifles, and nuclear weapons cannot be morally culpable, only people can be. In the name of greater personal freedom, both of conscience and property, governments ought not to restrict inquiry into, or ownership of, dangerous items. The law, codes of ethics, and public and private morality are well-equipped to deal with unethical uses of artifacts, so the principle of maximal freedom requires that we allow not only inquiry into, but possession of knives, rifles, and nuclear weapons (at least for certain nations). But this is not quite the case in practice, and we do tolerate restrictions on owning certain artifacts. Thus, in the U.S., even the most ardent gun aficionado cannot legally own a fully automatic weapon, to say nothing of a tactical nuclear bomb. Moreover, we do not restrict thinking about, and inquiring to an extent, laws of nature generally. Indeed, many of us would consider it immoral to restrict such thought or inquiry as an intrusion into matters of personal conscience. But does this necessarily imply that while the freedom of personal conscience enables us to think about and inquire into all the universe's natural laws, taking any and all further steps must escape moral judgment?

Take, for instance, the problem of child pornography. Do we hold a pedophile morally guiltless just because, while he might have amassed a collection of pedophilic literature or cartoons, he or she never actually abused a child or contributed to the abuse of a child? Notions of free speech and conscience might protect that behavior, but we are willing to not just judge certain further positive acts relating to pedophilia as not only morally blameworthy, but worthy also of legal culpability. Intentions matter, even when intention alone is not enough to spur public regulation. Stated intentions matter more, and even when they do not rise to the level of legal culpability, they may spark appropriate moral indignation or outrage. And finally, positive acts based on intention matter even more, and can provoke both appropriate moral indignation, outrage, or public recrimination. The pedophile who possesses photos, even while he or she might not have directly contributed to a harm, has indirectly done so and our moral outrage and legal repercussions grow accordingly.

The case of the pedophile might make us reconsider the notion that, while all thought and conscience should be totally free of external restriction, both are nonetheless immune to moral judgment. Similar cases may be made about individuals in both their personal and professional capacities who hold intentions, and even take positive actions without direct consequences or harms, yet that invoke some moral culpability. Do we hold the businessperson who thinks about the social or personal consequences of his or her actions in the same regard as one who does not, even where no real difference accrues to customers, colleagues, or society?

I argue that when considering the ethics of scientists, we must not only look at regulations, laws, and codes used to review or punish their actions, but we should also consider intentions and motivations with an eye toward education. Moral training of scientists, as with other professionals, presupposes not only that we wish to keep them from breaking laws or running afoul of professional codes of conduct, but also that we wish to help develop moral insight that can guide behaviors [10]. Take an example from another profession whose members affect peoples' lives daily, with sometime dire consequences. Even where an attorney, for instance, injures no one by his lies, the fact of the lie alone ought to concern us. Both in their individual and professional capacities, people who lie are not to be trusted and deserve our moral judgment. In professions like engineering, science, medicine, and law, moreover, the consequences of actions taken with ill-intentions matter much more to clients, colleagues, patients, and society as a whole simply because the potential for harms is so great.

We should take account of a broader moral horizon when considering the ethics and morality of scientists, just as we do with other professionals, and ask whether and when intentions and positive actions on those intentions trigger an individual duty to refrain, and subsequent moral judgment by others, even where the law or regulations ought not to be invoked. All of which brings us back to the scenarios presented at outset, and the problem of ice-nine as described by Kurt Vonnegut. Do the principles of beneficence, dignity, or justice provoke any ethical duties on scientists while inquiring into natural laws? Are these duties, if any, different in so-called "dual-use" cases than for instance in the case of nightmarish scenarios like ice-nine?

Smallpox, Ice-Nine, and Dangerous Things

Almost anything can be considered "dual-use" if we want to be technical. A nuclear bomb could be used to level a city, or to create a canal. Smallpox research could be used to develop new cures, new therapies, antiviral medications, or new biological weapons. Even ice-nine could serve a dual use, providing ice to skate upon in the middle of summer, or destroying the entire eco-system. For that matter, the most seemingly benign inventions could, given sufficient creativity, be put to questionable or immoral uses. Printing presses can produce great works of art, or hateful screeds. The dual-use debate, then, may be a bit of a red herring. We are concerned with the ethical implications of certain types of scientific research, and the capacity for a certain discovery or technology's dual-use is not what matters. Instead, we should ask under what conditions a scientist ought to refrain from either investigating some aspect of nature, and under what conditions he or she ought to disseminate certain knowledge, regardless of whether the science in question has both a beneficial or harmful use. Let's reconsider the issue of smallpox and its near-eradication.

The global public-health initiative to eradicate smallpox was nearly successful. Its final success was abandoned, and now, despite the fact that smallpox does not exist "in nature" it still exists, and poses a real threat to humanity. That need not have been the case. Because smallpox has no other vectors for its survival apart from human hosts, when it was finally eradicated from all human hosts its extinction could have been guaranteed. But for the fact that the U.S. and Soviet Union insisted on maintaining stockpiles of the virus, we would not need now to worry about the use by rogue states or terrorists of stolen quantities of smallpox. But for the efforts of the U.S. and the Soviet Union to "study" the use of smallpox in bio-warfare, and the mass-production and subsequent loss of control over the remaining stockpiles of smallpox virus under Soviet science, smallpox would be but a distant memory of nature's capacity for horror and destruction. Scientists cannot be held immune from the moral implications of having preserved stockpiles of the virus. Some made arguments based upon the value to science posed by continuing study of the nearly-extinct virus. Their arguments won the day, even if there may have been ulterior motives on the part of the two sponsoring governments maintaining the last known samples. Do any ethical principles mitigate against either the active encouragement of, or complicity with the decision to retain the last remaining smallpox samples?

Let's consider first the Belmont Principles. As it turns out, one of the big obstacles to conducting any legitimate science with smallpox is that it has no animal vectors. The Nuremburg code, and subsequent codes of biomedical ethics, require that human subject research be preceded by animal research. To do useful, beneficial research using smallpox would require a human subject, and no researcher could ethically employ human subjects in smallpox research. Not only would the danger be too great, but without first doing animal research, no human subject research could be approved. In the last-ditch effort to save the smallpox stockpiles in the U.S. in 1999, researchers proposed that a useful application of the smallpox samples was in attempting to find an animal model for the disease. Toward this end, researchers exposed monkeys to massive doses of smallpox until they finally sickened the subjects. Nearly every monkey exposed died without developing human-like symptoms of the disease. But a couple monkeys developed responses similar to human smallpox. This was written of as a triumph in smallpox research, and for some has justified the maintenance of the smallpox stockpile. Finally, a potentially useful animal model of smallpox infection may exist which now justifies maintaining the stockpiles so that further research can be done. And all of this is further justified by the very real potential that smallpox, while no longer a natural threat, is a threatened potential agent of bioterrorism [2]. In this context, what are the implications of the decision to preserve smallpox considering the principles of respect for persons, beneficence, and justice? Does an extended moral horizon alter our view?

If we consider that the subjects of the smallpox investigations (conducted in part to justify continuing to maintain smallpox stockpiles) include not just the monkeys that were infected and ultimately died, but also humanity as a whole, did this experiment satisfy the Belmont Principles? It would arguably meet these principles if smallpox remained a natural threat. The dignity of individual humans was not infringed. No individual was treated as less than autonomous or deserving of equal dignity. Moreover, if smallpox were still a natural threat, then presumably all experiments would be conducted with the goal of treatment or, as was the case before 1979, eradication. And finally, the principle of justice is satisfied as long as no vulnerable populations were treated less than equally in the course of the experiment. But if we consider the implications of the experiments in the context of a disease that could historically have been eradicated completely, then we can be more critical of the intentions of the scientists and their decisions to take part in the research. Let's imagine, since smallpox had been eradicated from the natural environment and only posed a threat from intentionally-maintained stockpiles held by humans, that smallpox and ice-nine pose nearly-identical risks, and are similar technologies. Ice-nine, like smallpox, posed no natural risk in Vonnegut's book, but only posed a risk as a human-devised technology. The dual-use argument that might justify experimenting with ice-nine breaks down in light of it's artificial nature. Moreover, the potentially catastrophic results of an accident involving ice-nine (namely, the total destruction of the biosphere) argue in favor of a positive duty not to investigate it beyond mere surmise or theory. Neither beneficence nor justice warrant investigating ice-nine. We might argue that beneficence argues in favor of investigating smallpox because we worry about terrorist uses of it and need to devise treatments. All of which is recursively self-satisfying, because we would not have had to worry about this had scientists done the right thing to begin with, and supported its ultimate destruction. In the world of Cat's Cradle, we could similarly argue in favor of ethically pursuing ice-nine research only in a post-ice-nine-apocalypse environment.

An argument that is often used to justify these sorts of scientific inquiries is that "someone will devise the technologies, and employ them harmfully -- eventually. Thus, we should investigate these things first (because we have good intentions)." Of course, this reasoning justifies investigating any and all science and technologies, no matter how potentially destructive or threatening to humanity or the environment. But it presupposes a) that the investigators doing the work have good intentions, 2) that the technology or discovery would eventually be carried out by others, and c) that once discovered or applied, it can be contained. Let's assume that, in fact, ice-nine, or smallpox for that matter, will come into the hands of individuals or groups with less-than-good intentions. Will discovering it, or investigating it now do any good? In the case of ice-nine, clearly the answer is no. In the case of smallpox, beneficence would argue for the research if for some reason we believed that smallpox could not be contained with existing technologies. If, for instance, we believe that the Australian "mousepox trick" could be applied to smallpox, then devising ways to treat genetically-altered mousepox might be an act of beneficence. But without an animal model for similarly altered smallpox, then we'd need first to try the "trick" on smallpox. Again, we have a recursive, self-fulfilling justification to pursue any and all research, including on any devastating, horrific, or deadly technology one can think of. Moreover, there's always reason to question whether one's own motivations will always be pure, or that a technology will always remain in one's control or contained.

The "Eventual" Fallacy

The "eventual" fallacy justifies any investigation, and scientific inquiry, no matter the potential consequences. It fails if we broaden the moral horizon offered by the Belmont principles to include humanity as a whole when we are considering sciences and technologies posing no natural threat. Implicit in bioethical principles is some utilitarian calculus. Science proceeds not in a vacuum, but as a socially devised institution. It is conducted by professionals, with funding from mostly public sources, and with relative freedom under the auspices of mostly academic environments. As a largely public institution, and as the beneficiaries of the public trust and wealth, scientists must consider the consequences of their inquiries. They are not lone, mad scientists, hunched over Frankenstein apparatus in private attics. Nor is worrying about the possible existence of Dr. Frankenstein sufficient to warrant all inquiries. Rather, science must be free to inquire into any and all of nature's mysteries, but scientists must also aware of being beholden to a world at

large, bound by concerns about consequences of their research, and ultimately dependent upon public support for their institutions.
The "eventual" argument makes sense when the risks posed by investigating a deadly thing are outweighed by the likelihood of that deadly thing's being discovered and used by others combined with the potential of a scientific investigation developing a plausible protection of the public at large. So, roughly:

R=risk,
L=likelihood of independent discovery and use, and
P=potential benefit from scientific investigation now.

If L+P>R, then a scientist can make a moral case for pursing an investigation into something posing a large, general risk. Otherwise, there is simply no moral justification for further inquiry. Taking ice-nine as an example:

R= 100 (near-likelihood of world-wide catastrophe if released into the environment)
L= 99 (being generous, on a long enough time-line, this number grows to 100)
P= 0 (there's no "cure" for ice-nine)

Or taking smallpox research (now, as opposed to before the eradication):

R= 90 (smallpox could escape and cause enormous human devastation)
L= 70 (there's a chance that Russian stockpiles have already made their way into others' hands)
P= 10 (we already have smallpox vaccines that work well, but maybe we can develop vaccines for other strains or genetically-modified versions)

Note that the value of P changes as the likelihood of potential independent discovery changes because of the temporal caveat. Thus, it is right to inquire into the state of scientific knowledge elsewhere. However, this imposes an additional burden not to increase the value of L by disseminating knowledge that leads others to dangerous knowledge where there is no supervening imperative due to potential benefits from the knowledge.

The "eventual" argument changes over time, and depending upon actual conditions in the world. If, for instance, we know that some rogue state or terrorist group has been experimenting with smallpox, then the calculus changes. It changes even more if we can identify the nature of those experiments and thus target scientific inquiry to a specific threat. But a generalized threat posed by the potential of someone acquiring knowledge or technology somewhere at some time means that this calculus requires scientific caution. For sufficiently deadly inquiries or applications, scientists should perceive a duty to refrain at least from disseminating certain types of knowledge, if not necessarily from theoretical inquiry alone (unless that inquiry may reasonably be justified by the above calculus). The "eventual" fallacy is committed by simple recourse to the truism that over an infinite time-span, all natural truths will be discovered, and all potential uses and misuses of technology will be developed, so present research on any science or application of technology is morally justified.

Implications for Institutions

Unlike the Belmont Principles, which could be used to guide the development of regulatory institutions, the expanded ethical horizon I have argued for above requires individual responsibility on the part of scientists. The calculus proposed must be employed by scientists before they ever get to the point of disseminating their ideas. It is a personal, moral responsibility that must be cultivated. Nonetheless, encouraging the development and adoption of these principles, and adopting the notion of a broad horizon of scientific responsibility (encompassing not just individual human subjects, but also responsibility toward humanity in general), can best be encouraged through new institutions. Legal and regulatory bodies ought to devise these institutions both within and among sovereigns. Professional organization as well ought to embrace and adopt ethical training of their members, understanding that scientists are citizens of broader groups whose funding and support they require. Education in principles not just of scientific integrity, but also social responsibility, ought to be developed and embraced. Currently, scientific integrity and ethics are taught only in the briefest and most superficial manners, and are not generally necessary for any scientist not doing human subject research. But in light of the potential for sciences and their technologies to be used for harm, and given the scale of some of these potential harms, more general education in science and morality should be required. This is especially true where the potential impact of a particular science is great, as with nanotechnology, genetic engineering, and similar technologies [11], [12].

As discussed above, scientists are generally beholden to public funding, at least to some extent, and just as many governments now require some minimum training in the core bioethical principles of Belmont and its offspring, so too could grant funding in technologies like nanotech and genomics depend on some minimum education in ethics.

Besides education, the principles and proposed calculus of risks, harms, and benefits, could be used in post-hoc analyses to determine culpability where scientists release dangerous sciences or technologies which actually cause harms. Just as medical doctors were culpable in the Nuremburg trials, so too might future scientists be morally and legally culpable for the apocalyptic (or even slightly less-so) repercussions of their negligence or recklessness. Of course, mens rea must be considered, but merely citing the "eventual" fallacy will not suffice to defend all scientific inquiry and its resultant dissemination, either through publication or technology. Scientists must not only have a sense that they are morally culpable for the uses of their discoveries where they understand the risk – harm - likelihood calculus, but they must also be liable to be held culpable where harms result from their acts, and where they possess a culpable mens rea.

Just as governments take it upon themselves to fund and advance research and development, both out of scientific curiosity and as a way to grow economically, so should they adopt the responsibility to educate scientists to be better citizens. As taxpayers provide for investigations into nature's truths, sometimes with no potential for economic benefit, they must also be considered as beneficiaries or targets of the fruits of scientific inquiry. An expansion of the Belmont Principles might include recognizing: we are all human subjects of certain inquiries. Where discoveries possess the potential of great harms, environmental catastrophes, mass extinctions, or worse, the collapse of an entire biosphere (as with ice-nine, or "grey goo"), scientists must take it upon themselves to measure their aesthetic appreciation of truths in themselves with gravity of worst-case repercussions. Institutions and regulatory bodies must encourage this, and provide guidance in the form of practical moral education of all scientists, not just in medicine and bioethics, but for all fields of inquiry. Teaching ethical principles to scientists need not stifle research. Nor does it imply that scientists must watch their thoughts. They need not restrict their thoughts, but they ought to guide them. Minds should be free to explore all possibilities, but the context for inquiry must always be considered to encompass something broader than just the institutions of science. Where one realizes grave or catastrophic implications for a particular path of inquiry, one does owe a duty to those on whose behalf you are musing, and who would inevitably become the target of resulting catastrophic technologies. Just as any of us may privately muse about acts of horror or violence, we assume greater duties as we begin to discuss, plan, or execute those acts. The same must be true form scientists, as in any other public profession or private life. Respect, beneficence, and justice apply not only to human subjects of particular experiments, but more generally to humanity as a whole. The result of all this should be better trust of scientists and their profession, and a greater realization on the part of scientists that their work proceeds through mutual trust and appreciation between scientists and the public. In the end, we all should benefit as scientists begin to realize their duties are personally-held, and broadly applicable. When faced with the choice to inquire into something whose only or most likely application is harmful or deadly, scientists should have the moral strength, educational background, and public support to refuse in light of ethical principles generally accepted, well considered, and backed by strong public institutions.

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3. Normative argumentation; the nuclear case

Suppose you are the members of the Dutch Parliament (Lower House). A majority in the Parliament has already chosen to seriously expand nuclear power in the Netherlands and as political decision-makers you are expected to recommend one of the two main fuel cycles for the production of nuclear power. As you will read in the following pages, these fuel cycles seriously differ in terms of their consequences for the people belonging to different generations. The question is now what you would choose based on the provided explanation. In answering this question, you need to at least be aware of the following sub-questions.

- ⇨ How did you weight the interest of different generations?
- ⇨ Would you consider the (potential) future technological possibilities in your recommendation?
- ⇨ Which generation is benefiting most from your recommended fuel cycle?
- ⇨ How would you rank environmental, public health, security and economic issues?

The aim of this exercise is to gain an insight into the possibilities and limits of argumentation to reach agreement on ethical problems in technological issues. In principle a thesis should be defended by real enthusiasts. However, as a person who defends a thesis should in principle be aware of the counterarguments, we invite you to exercise with defending an opinion that is not necessarily yours.

"Assuming that nuclear energy is one of the future energy options, the closed fuel cycle should be applied rather than the open fuel cycle in the production of nuclear energy."

The group will be split up as follows. One group (4-5 people) is formed by the enthusiasts of the thesis; a similar group will be the detractors. We aim at discussing the thesis by exchanging arguments that should be founded by technical information. There is also a group (4-5 people) of arbitrators that keep track of valid argumentation and fallacies. Here follows the set-up of the exercise:

1) The pro- and con-group both get 5 minutes to explain and argue for their position with respect to the thesis; no interruptions.
2) In a second round of twice 5 minutes, both parties get the chance to respond to the arguments of the other group; again no interruptions in this round.
3) The group of arbitrators, who has been silent so far, state their observations. The discussion-parties should take those remarks into consideration in the open-floor discussion.
4) After a coffee break, in the next round, the floor will be open for discussion. The arbitrators can now point out violations immediately. At this stage (20 minutes) the goal is to achieve agreement. Note that there is no guarantee that agreement about the whole issue will be reached. In case of remaining disagreement, isolate the points of disagreement and try to obtain agreement on your points of disagreement.
5) The last quarter of will be an evaluation to reflect on the whole discussion and the rules of reasoning and argumentation. If points of disagreement remain (which is usually the case) then try to answer te question whether the remaining disagreement is due to a lack of time or other factors that in principle could be repaired; or whether the disagreement is of a more fundamental nature that might not even be resolved in an ideal situation. You can here also consider how relatively homogeneous your group is. E.g., do you expect the political decision-making to substantially differ with your discussion?

3.1. To Recycle or Not to Recycle?[1]

3.1.1.Introduction

The worldwide need for energy is growing. The International Energy Agency foresees a 60% increase in energy need in the world between 2004 and 2030 and most of this expansion is expected to be met by fossil fuel [1]. Fossil fuels are not an attractive option, however, for reasons concerning the availability of resources and climate change. An increased need for alternative energy sources is therefore expected in the upcoming decades, e.g. wind energy, solar energy, but also nuclear energy. After being ruled out in many countries following the Chernobyl disaster in 1986, nuclear energy has recently made a serious comeback in the public and political debates about the future of energy. Many people consider nuclear energy at least as a serious alternative for the transition period between fossil fuels and sustainable energy sources. According to the World Nuclear Association, there were 435 operative nuclear reactors in January 2007; The United States, France, Japan and Russia together possess the vast majority of the operative reactors producing 370 GWe. As a whole, nuclear energy provides almost 16% of worldwide energy supply [2, 3].

The main advantage of nuclear energy—compared to fossil fuels—is its capability of producing a large amount of energy with relatively small amounts of fuel and a very small production of greenhouse gases. However, nuclear energy has serious drawbacks, such as accident risks, security concerns, proliferation threats, and nuclear waste. The waste problem is perhaps the Achilles' heel of nuclear energy as it remains radiotoxic for thousands of years [4].

Discussions about nuclear waste management must be related to the production of nuclear energy, as the most hazardous waste is produced during energy production. The question guiding this paper is whether spent fuel1 is to be disposed of directly or to be reused in the fuel cycle, referred to as the open and closed fuel cycle, respectively [5]. This issue is still topical after more than four decades of widely deployment of nuclear energy. In an open fuel cycle, uranium is irradiated once and the spent fuel is considered as waste to be disposed of directly. This waste remains radiotoxic for approximately 200,000 years; the period in which the radiotoxicity of spent fuel will equal that of the amount of natural uranium used to produce the fuel. Radiotoxicity is defined as the biological impact of radioactive nuclides on human health, in case they are digested or inhaled; these effects are indicated in sievert (Sv) or millisieverts (mSv). The closed fuel cycle reuses spent fuel after irradiation to produce energy and diminishes its toxicity and volume substantially. This fuel cycle has many long-term benefits, but it also creates extra short-term risks.

The question rises here how to deal with spent fuel in a proper way, taking the needs and interests of this generation and future generations into account. We should not foreclose options for future generations and should manage the waste in a such way that "will not impose undue burdens on future generations" [6, 7]. In this paper we approach "undue burdens" in the light of fuel cycles and propose intergenerational justice as a framework in order to choose between the fuel cycle: are we willing to transfer all risks of spent fuel to future generations, or do we find it more just to diminish risks and hazards of our waste to the maximum extent and accept, consequently, some additional risks to the present generation. We discuss the idea of having right towards future generation and the concept of intergenerational justice. We further present the two fuel cycles and identify the associated risks with these fuel cycles. In the following chapter, we focus on

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[1] The following text is drawn from the article 'To Recyle or Not to Recyle, An Intergenerational Approach to Nuclear Fuel Cycles' (Taebi, B., and J. L. Kloosterman 2008. To Recycle or Not to Recycle? An Intergenerational Approach to Nuclear Fuel Cycles. *Science and Engineering Ethics* **14** (2):177-200.)

conflicting values in choosing between them and reduce all trade-offs to a chief trade-off between the present and future generations. The next chapter provides a few underlying assumptions and possible counter-arguments.

Whether nuclear energy is desirable or indispensable as an energy source in the future is a controversial issue, which is beyond the scope of this paper. At the same time, applying nuclear energy through different fuel cycles raises a number of ethical concerns and moral dilemmas; on those issues we focus here. Moreover, the existing spent fuel all around the world is an urgent problem that needs to be dealt with. 280,000 tons of spent fuel had been discharged globally by the end of 2004, of which one-third has been recycled, leaving 190,000 tons of spent fuel stored; the growth rate is estimated on 10,500 tons a year [8, 9]. The choice between the open and closed fuel cycle has significant influence on this growth. These intergenerational discussions are also crucial for the future of research investments on waste management issues. Partitioning and transmutation (P&T) is a new technology for further diminishing the waste radiotoxicity. P&T is still in its infancy and needs serious investments to be further developed [10, 11]; these investment are justified if and only if one chooses the closed fuel cycle, of which the P&T could be considered as an extension.

3.1.2. Future rights, present obligations: intergenerational justice

Increasing concerns about depleting the Earth's resources and damaging the environment have invoked a new debate on justice across generations or intergenerational justice. This concept of justice was first introduced by John Rawls in 1971 as intergenerational distributive justice, which stands for an equal allocation of social benefits and burdens [12]. Justice for future implies that today's people have obligations towards their descendants [13, 14] and these obligations entail certain rights for the future [15–17]. These assumed rights have been challenged by some philosophers: "…the ascription of rights is probably to be made to actual persons—not possible persons" [18] and non-existing future people cannot be said to have rights, as our action and inaction define their composition and identity [19]; this is referred to as the Derek Parfit's 'non-identity-problem'. Other objections against these alleged rights are expressed as the inability to predict future properly, the ignorance of the need and desire for future as well as the contingent nature of future. There have been a variety of arguments provided in the literature to these objections2 [20–23]: William Grey has proposed "impersonal principles subject to retroactive person-affecting constraints" [24] and Wilfred Beckerman has argued that we should provide future people with the minimum opportunity for a "decent and civilised society" [25].

Although these fundamental discussions about right and obligation towards future people are very relevant, in this paper we will focus on the application of these assumed future rights to environmental policy and more specifically nuclear waste. In the last decades the climate change has given rise to serious concerns for the future [26, 27]. Do we have a duty to future generations [21, chap. 5] and if so what does this duty entail [28] and how should we realize it [29]?

Anticipating technological progress in a rapidly developing world and being concerned about future generations, the World Commission of Environment and Development introduced the concept of sustainable development in 1987. This moment designates the introduction of intergenerational concerns in environmental policy. This Brundtland definition—named after commission's chairperson—states that the key to sustainable development is an equitable sharing of benefits and burdens between generations "[…] that meets the needs of the present without compromising the ability of future generations to meet their own needs" [30]. The United Nations Conference on Environment and Development in Rio de Janeiro in 1992 (Earth Summit) not only endorsed this concept of sustainable development formally among 178 national governments, it also explicitly included the concept of equity in its principles [31, Principle 3].

The sustainability principle implies that there is a conflict of interest between the present and future generations. In an anthology edited by Andrew Dobson, the concept of sustainable development is evaluated in the light of intergenerational justice [32]. Wilfred Beckerman believes that the problems future people encounter have existed for millennia and states that our main obligation towards future people is "moving towards just institution and a 'decent' society", which encompasses future generations as well [33, p. 91]. Brian Barry investigates whether sustainability is a "necessary or a sufficient condition of intergenerational distributive justice". Barry emphasizes the obligations we have towards future generations and says that "measures intended to improve the prospects of future generations […] do not represent optional benevolence on our part but are demanded by elementary considerations of justice" [34, 35]3. Bryan Norton perceives of sustainability as "an obligation not to diminish the opportunity of future generations to achieve well-being at least equal to their predecessors." He further presents a model in order to compare well-being across time [36]. The "contested meaning of sustainability" in technology is comprehensively discussed by Aidan Davison [37].

What does the forgoing discussion about rights and obligations entail for nuclear fuel cycles, considering the fact that spent fuel life-time concerns a period between 1,000 and 200,000 years? The Nuclear Energy Agency (NEA4) introduces sustainability in one of its studies [11]. In this paper we adapt this definition both conceptually and practically and introduce intergenerational justice as a framework to choose between the fuel cycles. Intergenerational concerns have already been expressed about nuclear waste [38–40], but mainly with respect to the choice for final disposal of long living radioactive waste.

3.1.3. Nuclear Fuel Cycles: Open and Closed

The characteristic difference in the fuel cycles is how spent fuel is dealt with after irradiation. Two main approaches to spent fuel outline the main dissimilarity between these cycles: (1) the direct isolation of the material from the environment for a long period of time in which it remains radiotoxic and (2) 'destroying' or converting the very long-lived radionuclides to shorter lived material [5]. The first approach represents the open fuel cycle in the production of energy. The closed fuel cycle is in accordance with the second approach. Here below we will elaborate on these two fuel cycles.

Open Fuel Cycle (OFC): Once-through Option

In the OFC, the lesser isotope of uranium (235U) is fissioned—split—in light water reactors (LWR) to produce energy; 90% of all operative nuclear reactors to produce energy are LWRs. Natural uranium contains two main isotopes, which constitute 235U and 238U. Only the first isotope (235U) is fissile and is used in LWRs as fuel, but it only constitutes 0.7% of natural uranium. This low concentration is not sufficient in nuclear reactors, the concentration of 235U is therefore deliberately enhanced to a minimum of 3% through a process called uranium enrichment [4].

Irradiating uranium produces other materials, including plutonium (239Pu), which is a very long-lived radioactive isotope. Apart from plutonium-239, other fissile and non-fissile plutonium isotopes as well as minor actinides will be formed during irradiation. Actinides are elements with similar chemical properties: uranium and plutonium are the major constituents in spent fuel and are called major actinides; neptunium (Np), americium (Am), and curium (Cm) are produced in much smaller quantities and are called minor actinides. The presence of actinides in spent fuel defines the radiotoxicity and waste life-time. The OFC is also called the once-through strategy, as the spent fuel does not undergo any further treatment.

The spent nuclear fuel in an OFC will be disposed of underground for 200,000 years. This waste life-time in an OFC is dominated by plutonium. Neither minor actinides nor fission products have a significant influence on long-term radiotoxicity of waste in an OFC. Figure 1 illustrates these radiotoxicities. The dashed line represents spent fuel in an OFC, decaying to the ore level in approximately 200,000 years. Fission products are a mixture of various radionuclides that will decay to the uranium ore level after approximately 300 years [41], indicated by the dotted line in Fig. 1.

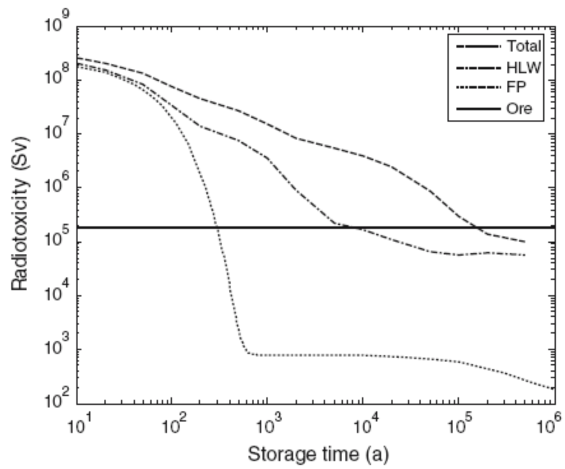

Fig. 1: Radiotoxicity of spent fuel, vitrified waste (HLW) and fission products, compared with regard to the radiotoxicity of uranium ore needed to manufacture the fuel

Closed Fuel Cycle: Recycling Plutonium and Uranium

As stated above, less than 1% of the uranium ore consists of the fissile isotope 235U. The major isotope of uranium (238U) is non-fissile and needs to be converted to a fissile material for energy production: plutonium (239Pu). Spent fuel could undergo a chemical treatment to separate fissionable elements including Pu, this is referred to as reprocessing. During reprocessing, uranium and plutonium in the spent fuel are isolated and recovered. Recycled uranium could either be added to the front-end of the fuel cycle or used to produce mixed oxide fuel (MOX), a mixture of uranium-oxide and plutonium-oxide that can be applied in nuclear reactors as a fuel [42] (see Fig. 2). Reprocessing is also called the "washing machine" for nuclear fuel. The irradiated fuel is "washed and cleaned" and "clean" materials (U + Pu) are reinserted into the fuel cycle to produce more energy, while the "dirt" is left behind (fission products and minor actinides) to be disposed of as high level waste (HLW) [4]. HLW contains fission products and minor actinides and will be put into a glass matrix in order to immobilize it and make it suitable for transportation, storage and disposal. This process is called conditioning of waste and results in so-called vitrified waste [6]. The ultimate radiotoxicity of vitrified waste will decrease to the uranium level in approximately 5,000 years [41], as illustrated by the dashed–dotted line in Fig. 1.

As uranium and plutonium are separated and reused, this fuel cycle is called the closed fuel cycle. The choice for a CFC is rightly associated with the choice to recycle spent fuel. Figure 2 illustrates various steps in both nuclear fuel cycles and their different interpretations of spent fuel. As can be seen in Fig. 2, the solid line representing the OFC is a once-through line. The CFC on the contrary is illustrated by separating plutonium and uranium and returning them to the fuel cycle, represented by the dashed lines. Nowadays, the main objective of reprocessing is to use uranium more efficiently and to reduce the waste volume and its toxicity considerably.

In the CFC, one can distinguish between two options with respect to nuclear reactors. In the first option, conventional LWRs are used, which are capable of using MOX as fuel. Reprocessed spent fuel is returned to the fuel cycle as MOX. Spent MOX fuel could again be reprocessed to separate uranium and plutonium. Further recycling of plutonium is only possible in another type of reactor capable of handling non-fissile plutonium: fast reactors, which constitute the second option. In the second option, the latter are basically used as energy producing reactors, in which MOX is the fuel. Due to the fast neutrons, fast reactors are capable of using the major isotope of uranium (238U) to the maximum extent via conversion to 239Pu [43].

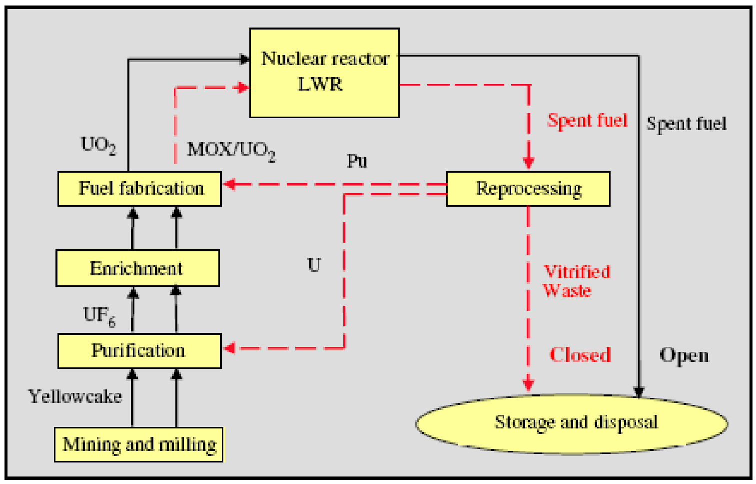

Fig. 2: An overview of the open and closed nuclear fuel cycle; the solid lines represent the OFC, the dashed lines the CFC

The Future of the Closed Fuel Cycle; Maximal Recycling

As spent fuel is conceived of as the Achilles' heel of nuclear energy, there have been serious attempts to further reduce its radiotoxicity and volume. A new method is partitioning and transmutation (P&T), which could be considered as a recent supplementary method to reprocessing. Spent fuel comprises uranium and plutonium, minor actinides and fission products. Uranium and plutonium are separated during reprocessing in order to reuse; P&T focuses on "destroying" minor actinides in spent fuel. If completely successful, P&T is expected to reduce the volume and radiotoxicity of spent fuel one hundred times (compared to OFC). After P&T, fuel radiotoxicity would decay to a non-hazardous level in 500 to 1,000 years [10]. The waste stream would then only consist of relatively short-lived fission products and curium isotopes. The latter will dominate the waste life-time and are considered to be too hazardous to be recycled at reasonable expenses and risks. P&T is merely available at the laboratory level at the moment; a considerable amount of R&D efforts is needed, before P&T could be utilized industrially [10, 11].

Waste Management, Interim Storage, Long-term Storage and Repositories

Irrespective of the fuel cycle choice, the remaining waste in a nuclear reactor after the (optional) treatments needs to be disposed. In waste management, a distinction is made between storage and disposal: storage means keeping the waste in engineered facilities aboveground or at some ten of meters depth underground, while disposal is the isolation and emplacement of the waste at

significant depth (a few hundreds of meters) underground in engineered facilities, called 'geological repositories'.
Until now, all the available storage facilities for spent fuel and high level waste have typically been above ground or at very shallow depth. Spent fuel is mostly stored under water for at least 3–5 years after removal from the reactor core; this stage is called interim storage. Water serves as radiation shielding and cooling fluid [39]. Bunn argued that interim storage for a period of 30–50 years has become an implicit consensus, as the world's reprocessing capacity is much less than globally spent fuel generation. In addition, there are no final repositories at our disposal yet. Interim storage of waste is also a crucial element in the safe management of radiotoxic waste since waste should be stored to allow radioactive decay to reduce the level of radiation and heat generation before final disposal. For the countries that favor reprocessing, spent fuel remains available for some decades to be reprocessed and there is no need to build up vast stockpiles of separated plutonium after reprocessing. For countries supporting direct disposal of spent fuel, interim storage allows more time to analyze and develop geological repositories appropriately [44].

A commonly proposed alternative to geological disposal is the long term monitored storage on the surface. Spent fuel remains in this case retrievable in the future. However, the technical community appears largely to disregard this option and considers the surface storage only as an interim measure until the waste can be disposed of in geological repositories [5, 38, 39, 45]. Deep oceans and outer space are mentioned as possible locations for final disposal as well, but there are substantial political, ethical as well as technical impediments, mainly related to the safety of these locations [5].

3.1.4. Risk and Associated Values

In this paper we distinguish moral values at play in the production of nuclear energy. Values are what one tries to achieve and strives for, as we consider them valuable; moral values refer to a good life and a good society. However, we should not confuse them with people's personal interest; moral values are general convictions and beliefs that people consider as worth striving for, in public interest [46]. We further identify dilemmas and moral problems rising from conflicting values: some trade-offs need to be made in order to choose a fuel cycle. The three main values we distinguished are as follows: sustainability, public health and safety and security. In the following sections we try to specify these values and, for the sake of comparison, relate them to risks and benefits of the open and closed fuel cycle.

We here distinguish between short-term and long-term effects, in which we consider the upcoming 50 years as short-term and after that as long-term. This period is chosen in view of comparisons in the literature between the fuel cycles: strong views about maintaining the OFC are mainly about the coming five decades [47] and in economic comparisons, short-term is defined as 50 years [48], probably based on estimations of reasonably assured uranium sources for the coming five to six decades in 2002 [49]. To conclude, 50 years is the period in which supply certainty of the OFC is assured. However, as will be shown later on, this period can be extended to 85 years or more without invalidating the arguments and conclusions of this paper.

Sustainability: Supply Certainty, Environmental Friendliness and Cost Affordability

A comparative study of the Nuclear Energy Agency (NEA) on various P&T technologies introduces the following three axes in order to assess sustainability: (1) resource efficiency (2) environmental friendliness and (3) cost effectiveness [11]. In this paper we take these axes as a guideline for understanding sustainability with respect to nuclear energy and follow an adapted version in terms of concepts and terminology, with regard to the fuel cycles.

Supply Certainty. On the first axis, sustainability refers to the continued availability of uranium: NEA uses the term resource efficiency for this. In this paper we apply the term supply certainty instead. Deploying resources efficiently means that we aspire to use as less as possible resources for the same purpose, while supply certainty refers to availability of resources in order to fulfill the needs. In energy discussion, certainty is a more significant concept than efficiency. Although this difference in designation has no consequences for the factual comparison in availability of uranium, we prefer the conceptually correct term.

As there are 50–60 years of reasonably assured uranium resources [49], there will be no significant short-term influences of the fuel cycle on the supply certainty. Later estimations of the NEA and the IAEA5 present approximately 85 years of reasonably assured resources (RAR) uranium are available for a once-through option in a LWR. These institutions estimate that this amount suffices for 2,500 years in a CFC, based on a pure fast reactor cycle, which is an improvement in supply certainty with a factor 30 [50]. Two later reports of the IAEA in 2006 adjust this period to 5,000–6,000 years, assuming that fast breeders allow essentially all non-fissile 238U to be bred to 239Pu in order to be used as fuel [8, 51]. It needs to be mentioned that these estimations are made under the explicit assumptions that fast breeders will be broadly deployed in the future.

The supply certainty benefits of the CFC will be relevant in the long run. Although there are no short-term significant differences between the fuel cycles, countries without natural fossil fuel, like Japan and France, tend to opt for reprocessing and recycling [52].

Environmental Friendliness: Radiological Risks to the Environment. The second axis of the OECD approach in specifying sustainability concerns environmental friendliness. This value depends on the accompanying radiological risks to the environment. Radiological risks, as we perceive them in this paper, express the possibility or rather probability that spent fuel leaks to the biosphere and can harm both people and the environment.

The NEA proposes three stages to assess radiological risks: (1) mining and milling, (2) power production, and (3) reprocessing. They compare the radiological risks of the OFC with the (once) recycled and reused MOX fuel. In the power production phase, NEA argues, there is no difference between the cycles. The main difference lies in the two other steps: mining and milling and reprocessing. They further argue that deployment of reprocessing decreases the need for enriched uranium and, therefore, natural uranium, of which the mining and milling involve the same radiological risks as reprocessing and reusing plutonium as MOX fuel. In fact, NEA argues that under the described circumstances there are equal radiological risks for both fuel cycles [53]. This argument is probably sound in the long run, for large scale reprocessing enterprises and under ideal circumstances, but one can wonder whether the factual short-term consequences are such that radiological risks of both fuel cycles are quite similar. The question remains whether we should take comparisons under ideal circumstances or factual consequences into consideration (in moral discussions). Furthermore, NEA completely neglects the distribution of benefits and burdens: building a reprocessing plant in France will increase local risks to the surrounding area and will diminish the burdens in a uranium-exporting country, such as Canada.

NEA further neglects the risks and hazards associated with the transport of waste in case of reprocessing: "…[R]adiological impacts of transportation are small compared to the total impact and to the dominant stage of the fuel cycle" [53]. If we consider different aspects of public perception of risk, we cannot retain the idea that radiological risks of nuclear waste transportation are negligibly small [54]. Only a few reprocessing plants are currently available around the world and spent fuel needs to be transported to those plants and back to the country of origin. In Great-Britain, for instance, a serious debate is currently taking place about the possibilities to return Japanese reprocessed spent fuel to Japan.

One of the serious counterarguments against reprocessing is the large investments needed to build the plants; small countries with a few nuclear power plants and in favor of the CFC will probably not build a reprocessing plant and will keep transporting spent fuel to those countries capable of this technology. To illustrate, The Netherlands is one of the countries with favorable reprocessing policy: Dutch spent fuel is currently transported to La Hague (France). There is no real chance that The Netherlands will build its own reprocessing plant in the coming years. To conclude, we assume that reprocessing will result in more short-term radiological risks, both to the environment and to the public health and safety, as illustrated in Fig. 3.

The short-term and long-term effects mentioned above also pertain to environmental friendliness. Using the fuel to the maximum extent and maximally recycling the spent fuel could be considered as long-term 'environmentally friendly', as the environment is less exposed to potential radiological risks and radiotoxicity in the long run. One of the main arguments in favor of reprocessing—along with enhanced resource efficiency—is the vast reduction of waste volume and its toxicity and the accompanying advantages from a sustainability point of view. The volume of each ton of spent fuel containing approximately 1.5 m3 of HLW could be reduced through reprocessing three times [55]. The waste toxicity will decrease at least with a factor three [52].

Affordability. The third axis the NEA proposes in its comparison is cost effectiveness. We adapt this axis here into affordability. We acknowledge the relevance of economic aspects for initiation and continuing a technological activity. Sustainability can be conceived of as durability, to that purpose. However, economic effectiveness goes much further than the question whether an activity is reasonably durable or affordable. Social security is, for instance, mostly ineffective economically but we consider that as a duty of the state with respect to its citizens; nevertheless, it is supposed to be neither economically effective nor profitable.

It is also arguable whether durability should be accepted as sustainability. This is an ongoing debate about different interpretations of the notion of sustainability. In a moral discussion, it is probably more just to separate economic considerations from other aspect of sustainability. However, for the sake of our analysis we follow here NEA's analysis and accept sustainability conceived as durability.

In 1994, a NEA study determined a slight cost difference between the reprocessing option and direct disposal. Based on best estimates and the uranium prices of that time, the cost of direct disposal was approximately 10% lower, which was considered to be insignificant, taking the cost uncertainties into account [56]. However, considering later uranium prices and resource estimations, there is a strong economic preference for the once-through strategy, even if a considerable growth of nuclear energy production is anticipated [52]. A MIT study in 2003 on 'The Future of Nuclear power' upholds the same view on economic aspects of reprocessing. Deutch et al. conclude in this report that—under certain assumptions and the US conditions—the CFC will be four times as expensive as the OFC. The once-through option could only be competitive to recycling if the uranium prices increase [47]. These MIT researchers are not susceptible to the counterarguments that disposing of reprocessed HLW will be less expensive. They furthermore present a cost model in which reprocessing remains uneconomic, even if the cost of reprocessed HLW were zero [47]. Another international study compares reprocessing with the once-through option and concludes that—even with substantial growth in nuclear power—the open LWR fuel cycle is likely to remain significantly cheaper than recycling in either LWRs (as MOX) or fast breeders for at least the next 50 years [48].

In the previous reasoning we considered reprocessing as a broadly applied technology, which will create the need to build new reprocessing plants. Economic affordability appear totally different if we base our analysis on the existing reprocessing plants, as many small consumers of nuclear energy reprocess their spent fuel in France or Great-Britain. These countries do not have excessive initial expenditures for their CFC.

Public Health and Safety: Short-term and Long-term Radiological Risks

The second value is public health and safety. We again distinguish between short-term and long-term radiological risks, which cause hazards to public health and safety. Recycling of plutonium as MOX diminishes the eventual radiotoxicity of spent fuel with a factor three, assuming that spent MOX fuel is disposed of after one use (also called once-through recycling6). Theoretically, multiple recycling of plutonium in fast reactors can decrease the long term radiotoxicity of disposed waste by a factor 10. These scientific achievements could be brought into practice in several decades [52].

Recycling spent fuel includes the separation and storage of plutonium. Along with security arguments which will be discussed later, plutonium contains serious potential risks to the public health due to its exceptional toxic nature. Plutonium needs especial isolation from humans, as it contains long-lived alpha emitters, which are very radiotoxic upon inhalation [57, p. 113)]. We included these risks in the short-term radiological risk for waste treatment. With respect to long-term radiological risks, the same reasoning as for the previously mentioned sustainability holds true: the short-term radiological risks associated with the CFC are significantly higher than the OFC.

Security and Proliferation Hazards

The last, but certainly not least value at play in waste management is security as a result of production of plutonium during recycling. Concerns regarding nuclear weapon proliferation are extremely relevant given the current state of world security. Proliferation threats rise either by the use of enriched uranium (up to 70%) or by the production or separation of plutonium. To illustrate, eight kilograms of weapon grade plutonium (239Pu) are sufficient to produce a Nagasaki-type bomb [58].

Proliferation is also a potential hazard in countries capable of enriching uranium. One of the main tasks of the IAEA is to annually report to the United Nation's Security Council about nuclear energy possessing nations. Although both the OFC and the CFC need enriched uranium in the reactor, the short-term proliferation concerns of the CFC are considerably higher, due to the separation of plutonium during reprocessing.

The security concerns are double-edged: reprocessing increases proliferation concerns for the contemporary people, but at the same time it decreases those concerns for future generations, since the spent fuel residuals contain no plutonium any more. One can argue that the potential proliferation concerns of direct disposal of spent fuel in the OFC are negligible compared to the actual security concerns in case of reprocessing: disposed spent fuel cannot be retrieved unnoted, and expensive and inaccessible reprocessing plants are needed to separate plutonium from it for weapon manufacturing. Some scholars argue, on the other hand, that spent fuel in geological repositories becomes a better weapon-grade material as time goes by, due to the natural enrichment of 239Pu [10]. However, this effect will take place in several thousands of years. In sum, the CFC involves more short-term proliferation and security concerns but decreases those concerns in the long run, as illustrated in Fig. 3.

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4. Ethical problems in the design of technology

4.1. Highway Safety Improvements[2]

David Weber, age 23, is a civil engineer in charge of safety improvements for District 7 (an eight-county area within a Midwestern state). Near the end of the fiscal year, the district engineer informs David that delivery of a new snow plow has been delayed, and as a consequence the district has $25,000 in uncommitted funds. He asks David to suggest a safety project (or projects) that can be put under contract within the current fiscal year.
From previous studies, David knows of two projects he believes should be completed as soon as funds are available. Site A is the intersection of Main and Oak Streets in the major city within the district; Site B is the intersection of Grape and Fir Roads in a rural area.
Pertinent data for the two intersections are as follows:

	Project A (Urban)	Project B (Rural)
Road traffic (vehicles/day)	24.000	6.000
Fatalities per year (3-yr average)	2	2
Injuries per year (3-yr average)	6	2
Accidents with only property damage (3-yr average)	40	12
Proposed improvement	New signals with turn lanes	Install signal
Improvement costs	$ 50.000,-*	$ 25.000,-

* Federal government will match state funds for this improvement since Main Street is part of the Federal Aid Primary System; hence, state will have to provide only $25,000.

A highway engineering textbook includes a table of average reductions in accidents resulting from the installation of the types of improvements David proposes. The tables are based on studies of intersections in urban and rural areas throughout the United States, over the past 20 years.

	Urban	Rural
% reduction in fatalities	50	60
% reduction in injuries	50	60
% reduction in Accidents with only property damage	25	-50*

* PD (property damage only) accidents are expected to increase because of the increase in rear-end accidents due to the stopping of high-speed traffic in rural areas

2 From: C.E. Harris, M.S. Pritchard & M.J. Rabins, Engineering Ethics: Concepts and Cases (Belmont etc.: Wadsworth, 1995, pp. 180-181: Case 6.3 Highway Safety Improvements. Some of the data has been adapted.

David recognizes that these reduction factors represent averages for intersections with a wide range of physical characteristics (number of approach lanes, angle of intersection, etc.); in all climates; with various mixes of trucks and passenger vehicles; various approach speeds; and so on.

Finally, here is some additional information that may be useful.

(1) In 1975, the National Safety Council and the National Highway Traffic Safety Administration both published dollar scales for comparing accident outcomes, as shown below:

	NSC	NHTSA
Fatality	$ 52.000	$ 235.000
Injury	3.000	11.200
Property damage	440	500

(2) Note that the 'exposure to hazard" is significantly higher for the drivers entering the rural intersection under present conditions.

(3) Individuals within the two groups pay roughly the same transportation taxes (licenses, gasoline taxes, etc.), hence, the collective taxes for the drivers entering the urban intersection are four times as much as for the group entering the rural intersection.

4.2. Questions:

1. If you were the engineer, which of the two projects A (urban) or B (rural) would you select for execution, and why? Explain whether the considerations mentioned under (2) and) above are relevant for your choice.

According to one reading of utilitarianism, governments should aim at maximising total social benefit. This means that governments should execute projects that maximise the sum of individual net benefits while disregarding the distribution of costs and benefits over individuals. It may happen that in a project thus selected, some individuals experience net harm or costs. Often, Kant's ethical theory is said to be opposed to this, as this theory requires that the rights or well being of all individuals should be respected or protected in the first place.

2. Does it affect your choice whether you adopt the one or the other of these two ethical principles?

3. Make explicit what the relevant ethical principle is that you (perhaps implicitly) had assumed in your own analysis that was at the basis of your choice at question 1 above.

4. Does your choice lead to a Pareto Improvement? Include in your consideration the fact that all citizens have paid taxes for the provision of public goods including traffic lights.

5. Decisions like this one on highway safety improvements are ultimately decisions on how tax money should be spent. Do you think that in reality it is engineers who make or should make such decisions? If not, who else should take such decisions, and what should be the proper role of engineers?

6. Assume that the traffic light decision is in reality made by the community council, the members of which have been elected by the citizens. As we have seen above, any decision on the issue requires the assumption of an ethical principle, whether the urilitarian principle, the Kantian principle, or yet another one. The council members may disagree on the choice of the ethical principle annd hence on which project should be selected. (Some citizens and their representers may be utilitarians, others may be Kantians or rights ethicists, and so on.) According to which voting rule should the council decide? Is it ethically correct to decide the issue by majority voting? Why? Would majority voting guarantee Pareto improvement?

7. Discuss the potentially detrimental effects that external subsidies (like the federal subsidy of $25.000 for project A) may have on collecive decisions if considered from the utilitarian point of view.

5. The Challenger launch decision

5.1. Role-play. The challenger launch decision

5.1.1. The accident with the Space Shuttle Challenger

On January 28th 1986, 11:38, Space Shuttle Challenger was launched from the Kennedy Space Centre, Cape Canaveral, Florida. It had a crew of seven persons, among which a school teacher, Christa McAuliffe, who was going to teach from space: hence the nickname of "Teacher in Space mission" for this launch. 73 seconds into the launch there was an enormous explosion; the Challenger disappeared into a cloud, and the remaining pieces fell into the ocean. All seven crew members died.

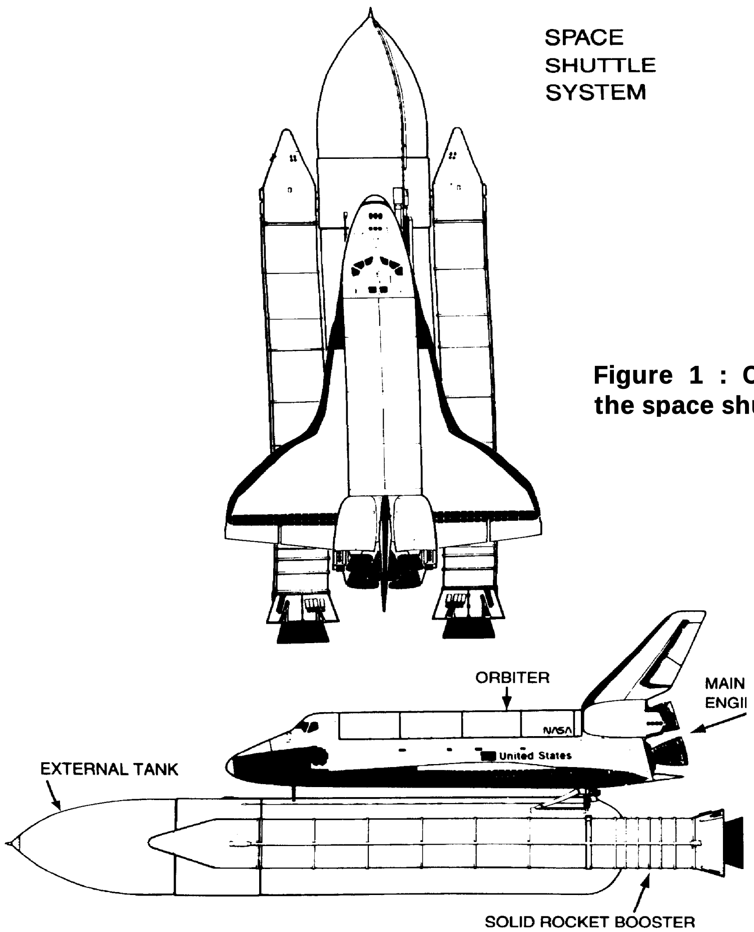

Figure 1 : Configuration of the space shuttle system

The prestigious space shuttle programme of NASA was immediately stopped, and a few days later the then president Ronald Reagan appointed a commission, led by senator William Rogers, with the assignment to research the causes of this disaster. Fairly soon after the accident there was a hypothesis what the cause could have been, in part from an analysis of the available video footage. In this footage it appears that a flame originates in the side of the right Solid Rocket Booster (SRB); it was then assumed that this flame burnt a hole into the external hydrogen tank leading to the explosion.

Soon also internal NASA memoranda came to light from which could be deduced that it had been known for some time that there was a problem with the O-rings sealing the joints between the parts of the SRBs. These SRBs are re-used in the space shuttle concept: when the fuel is spent they fall back to earth and are fished out of the ocean. In order to facilitate transport and re-fuelling, they are taken apart. However, on ignition the pressure difference between in- and outside of the SRB is enormous. The sealing thus has to perform a tough job, and it was known, from studying the seals of used SRBs, that with some regularity there was erosion of the O-rings. Morton Thiokol, the NASA subcontractor that had designed and produced these SRBs and that each time had to make them ready for launch, had even formed a taskforce to deal with the O-ring problem.

Furthermore it became known that on the evening before the launch there had been a teleconference between NASA Marshall Space Centre and Morton Thiokol Engineering in Utah. During this teleconference, Morton Thiokol had initially advised not to launch the shuttle. They were concerned about the behaviour of the O-rings at the extremely low temperatures that were being forecast. At such temperatures, the O-ring material would be harder and less elastic. However, after discussion Morton Thiokol withdrew their negative advice, resulting eventually in the disastrous launch. As soon as this emerged, the focus of the Rogers-commission became mainly concerned with the following question: why was the initial negative advice withdrawn and changed into a positive advice, and what roles were played in this process by the various involved individuals?

After the fact it is, of course, easy to denounce the decision taken in the teleconference as wrong. After all, the launch ended in catastrophe. Consider, however, that no absolute safety is (or even can be) claimed for space flight – as, indeed, for almost any large technological project. In other words, it may well be that the launch decision was very justifiable, and that this accident was imply a case of bad luck. The fact that things went wrong does not necessitate the conclusion that the risk that was taken was unacceptable.

Moreover, the launch decision was taken in a hierarchical organisation, and under political and commercial pressure. This is relevant for two reasons. Firstly, it is never only a technical (factual) question that is at issue: the question, "Is it safe to launch?" is a normative question, and therefore never answerable on purely technical grounds. Secondly – and this is what is emphasised by this role-play – there is a complex network of people that is involved in taking the decision, every one of them with their own competences and responsibilities, and as a consequence, own interests. Is it, in such a situation, exactly clear who is responsible for what? Whatever the answer may be to these questions: as a future engineer you would do well to ask the question, "could I have done a better job in that situation? A lot is to be learnt from this accident by taking this question as point of departure.

The above description of the Challenger disaster is of course not very detailed; in the context of this course we hardly have the time to do much better. Consider, however, that in your future professional practice also you will regularly have to take decisions without full knowledge of all relevant details, or even a full understanding of what all relevant details are. Furthermore, it is not the case that everybody has access to the same information; in part this is due to the hierarchical structure of, and division of labour within, organisations.

5.1.2. The role-play

At the tutorial we conduct the teleconference discussion about the launch advice, in the form of a role-play. Students are invited to crawl into the skin of an individual that was factually involved, and get a detailed description of this individual's position and tasks within the organisation, their worries, priorities and interests, and the information available to them. *Note: this means that (initially at least) not everybody has the same information.* The aim of the exercise is **not** to conduct exactly the same discussion as the one that actually took place, and to reach the same conclusion. Your assignment is to come to the best possible decision regarding a launch advice, within the limits of available information and time, and respecting the formal hierarchical relations between you.

The role-play extends over the following three episodes: (1) the preparation for the teleconference, (2) the teleconference itself, and (3) the aftermath of the teleconference (preceding the planned launch)*. Again, it should be stressed that you should try to abstract from your knowledge of the disastrous consequences of the actual launch.* (Those who want to know what actually took place during the teleconference should consult Diane Vaughan*, The Challenger launch decision: risky technology, culture, and deviance at NASA*, Chicago: 1996, chapter 8.) Not everybody gets a role; there are also impartial observers who will have the opportunity to ask questions about the actions and decisions of those who do have a role. These observers also have to check whether everybody communicates with each other in a way that is consistent with hierarchical structure; in the heat of the exercise it is easily forgotten that one is on a less equal footing than in real life. In order to really learn something from the role-play, and to keep it interesting, it is expected of the participants that they keep to their role and the rules and conditions attached to this role.

Involved individuals:
(In reality there were 34 persons at 3 locations involved in the teleconference, but we have to reduce this number for practical reasons)

<u>In the Marshall Space Centre</u>:
George Hardy, deputy director science and engineering directorate, NASA.
Lawrence Mulloy, manager solid rocket booster project, NASA
Stanley Reinartz, Shuttle projects office manager, NASA

<u>At Morton Thiokol, in Utah:</u>
Joe Kilminster, vice-president, space booster programs
Robert Lund, vice-president engineering
Roger Boisjoly, staff engineer
Arnold Thompson, engineer supervisor.

Each of these individuals receives their own information pack. Use name tags or similar to be able to correctly remember and identify your respective roles.
All those who have not been assigned a particular role are observer. See 1.3 below for your task and preparation.

Moments acted out in the role-play: (between brackets, the available time in the tutorial):

1. **<u>Before the teleconference</u>** *(15 minutes)*

The teleconference was scheduled at the request of Morton Thiokol, in reaction to next day's weather forecast. In what way do Morton Thiokol prepare for the teleconference? What conclusions can or must be drawn from available data? Do they agree in advance on the position they want to take during the teleconference? Consider that the motivation for your position is at least as important as the exact contents of it. The exact contents of a position leading to a negative recommendation for launch may vary; and a position that is in itself reasonable may succumb due to incomplete or plain bad motivation and argumentation.

At Marshall Space Centre as well it is important to assess the available data and conclusions that may be drawn from these data; moreover, it might be helpful to form a hypothesis about what position Morton Thiokol will take. To what extent is it possible, and are NASA willing, to postpone the launch because of a problem with the O-rings in the SRBs? Is NASA's aim to take a monolithic position vis a vis Morton Thiokol?

During this preparation stage you should only talk to people at the same location; you should consult them at length. Who is taking the lead in these preparations? Make a list of points to consider during the teleconference, or write down any argument that you want to present in a couple of lines. If applicable, prepare a visual presentation of your information (e.g. sheets) for the teleconference (this is recommended). Also, consider systematically: what is my responsibility here? What are my interests? What do I stand to gain or lose in each of the possible outcomes of the teleconference and, thereafter, the possible launch?

2. **The teleconference itself** *(max. 45 minutes)*

Be aware that a teleconference is in practical respects very different from a meeting at one location. The sheets, for example, were faxed and could therefore not be pointed at by the person who made them; it may not always be clear who is talking and who is present; and there is a tendency to talk between participants at the same location. Simulate this by sitting at opposite sides of the room. If needed, the teleconference may (as happened in reality as well) be paused in order to have (brief) local discussion. (This may be a good time for a coffee break – however, NASA and Morton Thiokol should not drink coffee together!)

Important matters that should be covered are: what is Morton Thiokol's recommendation, and what are the arguments supporting it? Is there a consensus within Morton Thiokol what the recommendation should be, and are the arguments for it consistent and cogent? Does it become clear what the ins and outs of the technical problem are, and how the seals might behave in case things go less well than perfect? What is NASA's reaction to Thiokol's recommendation? Which party has the burden of proof for the safety of the launch? Is there anybody whose opinion is decisive for which recommendation comes out of this teleconference? If so: who is it, and is it clear to everybody?

3. **After the teleconference: the decision whether or not to launch** *(10 minutes)*

After the teleconference, who are informed about its taking place and its outcome(s)? Is this (and the way things went during the teleconference itself) in accordance with the formal Flight Readiness Review procedure? If there is any doubt or lack of agreement at either Thiokol or NASA about the recommendation given, what does this lead to? Perhaps there are individuals that are inclined to blow the whistle, given the conclusions of the teleconference; what are their possibilities to do so, and how effective do you expect them to be?

This third moment should be distinguished from the **evaluation**, for which everybody abandons their role. Try to formulate common conclusions: Which decisions were taken, why, and (how) are they justifiable? Did the role-play diverge from what happened in reality; if so, why? Did this role-play make you change your mind about whether the actual launch decision was right? Has it become clearer how organisational structures have played a role in taking the decision? How well did the communication go, and have the technical arguments become completely clear? Can anyone be designated as ultimately responsible for the decision taken?

Sources:

Diane Vaughan, *The Challenger Launch Decision: Risky Technology, culture, and deviance at NASA*, Chicago (1996)

http://www.cwru.edu/affil/wwwethics/boisjoly/RB1-0.html

5.1.3. Observers

As interested outsider you don't know a great deal about the ins and outs of the Space Shuttle programme. NASA remains NASA, and the Cold War is still going on, so there is a fair amount of secrecy. It is clear, though, that the Space Shuttles are the pride of the nation. Within 8 years, there have already been 36 launches. With some regularity, launches are postponed, however safety margins in space flight are of a different order than those in public transport. On the other hand, though, tomorrow for the first time there will be a non-professional astronaut on a space flight: Christa McAuliffe, "teacher in space".

Because of some twist of fate you have the opportunity to attend a teleconference between NASA and subcontractor Morton Thiokol (manufacturer of the solid rocket boosters), at the eve of the launch of the "Challenger". It appears that they are worried about the low temperatures that are being forecast, and the behaviour of some kind of seal at these temperatures. Of course you are not expected to take part in the discussions during the teleconference, but should there be any major unclarities – either about technical details, or about anybody's motives – then you can of course pose questions about that.

Information:

- Organisation structure of NASA, and of Morton Thioko, available at Blackboard.

Preparation: study the organisation structure in order to understand where exactly the individuals in this role-play are. Who according to you should be the one deciding what launch recommendation is given after the teleconference?

5.2. The Space Shuttle tragedy and the ethics of engineering

By Steven Goldberg[3]

In the aftermath of the Space Shuttle Challenger accident individual villains were hard to find. Most observers, including the Presidential Commission investigating the matter, criticized instead the process that resulted in a launch despite concerns about O-ring seals that ultimately failed.

But if villains in the Challenger tragedy were scarce, heroes did emerge. They were the engineers at Morton Thiokol who, we were told, "objected to the launching,"[4] but were ignored both by company management highly pendant on the National Aeronautics and Space Administration (NASA) and by NASA officials under outside pressure to launch.[5]

Yet a close examination of the role of one of the most prominent engineer "resisters"[6] in the Space Shuttle case suggests that in fact heroes may be as scarce as villains. That examination, based on the report of the Presidential Commission, reveals an honest, competent engineer performing his work well, but it reveals as well an individual limiting himself strictly to his engineering, careful not to infringe on management prerogatives. In short, we have someone playing to perfection his

[3] Associate Professor of Law. Georgetown University Law Center. Washington, D.C. 20001. The author thanks Jerome Holmes for his excellent rescearch assistance.

[4] Kruglanski, *Freeze-think and the Clallenger*, 20, PSYCHOLOGY TODAY 48, 49 (1986).

[5] Editorial, *The Challenger Report*, Washington Post, June 10, 1986, at A18.

[6] GIazer & Glazer, *Whistleblolwing*, 20, PSYCHOLOGY TODAY 37 (1986).

assigned role in the decision making process; not a villain to be sure, but not a hero either.

Roger Boisjoly, at the time of the Challenger launch, was a member of the Seal Task Force at Morton Thiokol.[7] Unlike some of the other engineers involved in the decision to launch, Boisjoly did not have management responsibilities.[8] The night before the launch, in a teleconference involving Morton Thiokol and NASA officials, Boisjoly expressed "deep concern,"[9] as he had on previous occasions, about launching at low temperature.[10] The concerns were important because low temperatures were forecast for the next day. Boisjoly argued that at low temperatures, if erosion damaged the primary O-ring seal, "there is a higher probability of no secondary seal capability."[11] Boisjoly conceded that he had no data to quantify his concerns,[12] but initially his arguments led to a Morton Thiokol recommendation during the teleconference that the launch be postponed.[13] After further discussion, Morton Thiokol requested to break off the teleconference for a caucus.[14] At the caucus, Boisjoly continued to press his concerns. Morton Thiokol officials then said "we have to make a management decision."[15] Management, without including non-management personnel such as Boisjoly, reviewed the engineering facts as they knew them, concluded it was "a judgment call and therefore a management decision," and decided to recommend a launch.[16] The teleconference was resumed and NASA was informed that in Morton Thiokol's view if the primary seal did not succeed the secondary seal would and the launch could go forward.[17]

In hindsight, of course, Morton Thiokol's decision was wrong. But at the time, what was Boisjoly's attitude toward being excluded from the management caucus? Was it outrage? Far from it:

> I must emphasize, I had my say, and I never [would] take [away] any management right to take the input of an engineer and then make a decision based upon that input, and I truly believe that. I have worked at lot of companies, and that has been done from time to time, and I truly believe that, and so there was no point in me doing anything any further than I had already attempted to do.
>
> I did not see the final version of the chart until the next day. I just heard it read. I left the room feeling badly defeated, but I felt I really did all I could to stop the launch.[18]

There is a name for Boisjoly's approach. It is not heroism, it is separatism: the notion that scientists and engineers should supply the technical inputs, but appropriate management and political organs should make the value decisions.[19]

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[7] Presidential Commission on the Space Shuttle Challenger Accident, Report to the President, Vol. I, pp. 92, 107 (1986). Morton Thiokol, Inc. was the contractor for the shuttle's dolid rocket motor. *Id.* at 9.
[8] Rober Lund, for example, was an engineer who also was a vice president of Morton Thiokol. *Id.* at 92, 93, 107.
[9] *Id.* at 88.
[10] *Id.*
[11] *Id.*
[12] *Id.* at 89.
[13] *Id.* at 89,90
[14] *Id.* at 90.
[15] *Id.* at 93.
[16] *Id.* at 93.
[17] *Id.* at 96.
[18] *Id.* at 93.
[19] The term separatism was used prominently in a 1980 symposium on administrative law. See Yellin, *Sience, Technology and Administrative Government: Institutional Designs for Environmental Decisionmaking*, 92, YALE L.J. 1300, 1309 (1983); Carter, *Separatism ans Skepticism*, 92 YALE L.J. 1334 (1993). The idea of course is much older: much of the literature is discussed and analyzed in McGarity *Substantive and Procedural Discretion in Administrative Resolution of Science Policy Questions: Regulating Carcinogens in EPA ena* OSHA, 67 GEO. L.J. 729 (1979).

I use the term separatism in this piece simply lo refer to the attempt to separate out technical from policy decisions, not to suggest that technical decisions must be made by some new institution such as a science cour. *Cf.* Yellin, supra, at 1307.

Roger Boisjoly was not the only engineer at Morton Thiokol who adopted the separatist approach.

Separatism is the dominant approach today to policy problems of this type, and it is an approach that has been explicitly applied to engineers:

> As a class, engineers have neither the power nor the right to plan social change. If they did, we might be well on our way to George Orwell's 1984. Fortunately, engineers are no more agreed upon how to organize the world than are politicians, novelists, dentists, or philosophers. Should we risk oil spills and increase our reserves by off-shore drilling? Accept the hazards of pesticides in order to feed hungry people? Stop building a dam and thus protect an endangered fish? These are political questions; it is pathetic and a little frightening to see citizens abdicate their responsibilities by assigning them to the realm of engineering ethics.[20]

The Challenger accident is a case where the engineer was more cautious than management, but separatism operates, of course, in both directions. A nuclear engineer might believe that a one in a thousand chance of an accident over forty years of reactor operation is an acceptable risk, but, under the separatist approach, that is not the engineer's decision to make. The question of how much risk is acceptable is not an engineering question.

This is not the place to debate the pros and cons of separatism. It would be unfair, of course, to argue that the Challenger example alone proves that separatism is flawed. Surely engineers, left to their own devices, would sometimes make decisions that proved disastrous. But Boisjoly's experience is a dramatic example of separatism at work, and thus it does raise valid questions about what more, if anything, Boisjoly could have done consistent with the separatist model. As we noted, Boisjoly testified that there "was no point in . . . doing anything any further"[21] once management began its caucus. Is it true, however, that any further action would have run afoul of the idea that technicians should not usurp social judgments?

Separatism has always included the idea that experts can participate in public debates concerning value choices, but they do so as citizens, not experts. Yet surely there are also cases where even a devout separatist would agree that an individual scientist or engineer should speak, as an expert, outside of the usual chain of command. If, for example, an engineer believes his or her technical judgments are being suppressed or distorted, and lives are at risk, few would doubt that a dramatic public statement was justified. Indeed, such a statement would serve the separatist goal of informed public opinion. The issue ultimately becomes one of individual moral choice: to use the currently fashionable parlance, at what point does "whistleblowing"' become justified?

In Boisjoly's case whistleblowing might have included midnight phone calls to national news media or top NASA officials with the stark warning that if the launch took place, critical seals would fail and disaster would follow. Of course that effort might not have stopped the launch, but would it have been morally justified?

On the current record, it is impossible to know. It is unclear whether Boisjoly believed his technical arguments were improperly ignored or whether management simply disagreed with him on a policy matter. In addition, it is unclear to what extent Boisjoly was aware that his concerns were not fully passed along to NASA officials who had to make the final decision on the launch.

Even apart from the specific facts of Boisjoly's case, there are three general problems that hinder efforts to assess when whistleblowing is appropriate for an

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Rober Lund, an engineer and vice president, *see* note 5, *supra*, was skeptical about the launch at first, but when asked by company officials "to take off his engineering hat and put on his management hat." het supported the launch. PRESIDENTIAL COMMISSION, *supra* note 4, at 92-94.

[20] Florman, *Moral Blueprints: On Regulating the Ethics of Engineers*, HARPERS, October 1978, at 30, 32. Samual Florman is a prominent author in the field of engineering and engineering ethics. *See e.g.,* SAMUAL FLORMAN, THE EXISTENTIAL PLEASURES OF ENGINEERING (1976). For criticisms of portions of his work, *see* ROBERT J. BAUM, ETHICS AND ENGINERING CURRICULA 9-10 (1980); MIKE W. MARTIN & ROLAND SCHINZINGER, ETHICS IN ENGINEERING 159-160 (1983).

[21] *See* text accompanying note 15, *supra*.

engineer. First, the applicable ethical and professional standards for engineers working in large enterprises are surprisingly murky. There are difficult questions of professional responsibility when loyalty to an employer comes into conflict with concerns for the public.[22] Engineering, where employment in large corporate or government bureaucracies is the norm, has long been marked by an unclear and poorly-enforced set of professional norms monitored weakly by a fragmented collection of professional societies.[23] While some modern codes of conduct for engineering groups now say that "engineers shall hold paramount the safety, health and welfare of the public,"[24] enforcement of this idea has been extremely limited.[25]

Second, even if whistleblowing is called for, it is unclear what audience the engineer should alert. Most discussions assume, as we have to this point, that the media or bureaucratic higher-ups are the appropriate target. But are those groups always in the best position to assess the information the engineer has to offer? One alternative would be to alert precisely those who will suffer if an accident occurs. Often in engineering that is not realistic, since a large and undefined public will be affected by the proposed bridge or reactor. But if there is a more specifically definable public, why not alert them? The analogy, of course, would be informed consent, and while it is rarely invoked in discussions of engineering ethics,[26] it is worth considering whether the analogy is appropriate where, as here, the "subjects" of the engineer can be identified. In short, a phone call from an engineer to the astronauts themselves might have been the proper channel for whistleblowing here.

The final difficulty that prevents a fair assessment of what a dissenting engineer in the Challenger case might have done is an intensely practical one. Whistleblowers get fired. Put more cautiously, there are inadequate mechanisms in place to protect private sector whistleblowers from retaliatory discharge.[27] Boisjoly himself, who spoke out to the public only after the launch and after complete vindication, was temporarily transferred, perhaps in retaliation.[28] A government whistleblower has said, "If you have God, the law, the press and the facts on your side, you have a 50-50 chance of winning."[29] For an engineer in the private sector, those odds are optimistic.

In short, if Roger Boisjoly had spoken out the night before the launch he would have been a hero, risking everything for the sake of his obligations to others. As it was, he was a capable engineer in a separatist system who at least had the courage to speak out after the fact. An examination of his role reveals separatism at work, without the safety-valve of a workable system for bringing forth suppressed or distorted technical views. Under that system it is predictable that quite often if we do not have heroes we will have disasters.

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[22] This conflict is presented as the initial and central "engineer's dllemma"' in STEPHEN H. UNGER. CONTROLLING TECHNOLOGY: ETHICS AND THE RESPONSIBLE ENGINEER 1 (1982). *See generally* MARTIN & SCHINZINGER, supra note 17.

[23] The classic study of the American engineering profession from its origins through the New Deal is EDWIN T. LAYTON, JR., THE REVOLT OF THE ENGINEERS (1971). For more recent developments, *see* BAUM, *supra* note 17, at 8-10.

[24] Kultgen, *The Ideological Use of Profesional Codes*, 1, BUS. & PROFESSIONAL ETHICS J. 57-59 (Spring 1982).

[25] *Id.*

[26] For a notable exception, *see* MARTIN & SCHINZINGER, *supra* note 17, at 59-60; *see also* Long, *Informed Consent and Engineering: An Essay Review*, 3 BUS. & PROFESSIONAL ETHICS J. 59 (Fall 1983).

[27] *See, e.g.,* BAUM, *supra* note 17, at 61-62.

[28] *See e.g.,* Isikoff, *NASA Probes Thiokol's Treatment of Two Engineers*, Washington Post May 14, 1986, at A4.

[29] Glazer & Glazer, *supra* note 3, at 42.

6. Multinationals in non-Western countries

The reader discusses questions of cultural and ethical relativism in section 3.5. Applied to multinationals in non-Western countries, ethical relativism says that activities are morally allowed if they comply with local customs or laws. In this session we consider whether the activities of Western multinationals in non-Western countries could be justified by relativistic ethical theories and arguments. More specifically, we will try to shed light on the question of which differences in local customs and laws, if any, may be ethically exploited by a multinational in pursuing its business goal to maximise its profits.

We focus on a specific case, the Union Carbide chemical plant at Bhopal, India,
and the ensuing Bhopal disaster. By analysing the case and by answering the question of who was responsible for what, we will enhance our insight as to how similar failures can be prevented in the future.

The present case gives us occasion to explore the actual and possible role of (international) legislation in preventing failures such as the Bhopal disaster from happening. There is a connection here with a later working group session on responsibility and liability for environmental damage. In that session a similar question arises regarding the possibilities of legal systems for fostering responsible management of technology.

6.1. Bhopal

In the early hours of December 3rd, 1984, a cloud of poisonous methylisocyanate (MIC) escaped from the Union Carbide pesticide plant in Bhopal, India. Eventually more than 3000 people died, and more than 200.000 inhabitants of Bhopal were injured. This may be a low estimation: there was never agreement on the exact number of casualties. Neither was there agreement on the actual chain of events leading to the accident.
The victims were both employees of the Union Carbide plant and inhabitants of the neighbourhoods downwind from the plant. Originally, the plant had not been located within a residential area, but the town had "caught up" with it.
An accident such as the one in Bhopal raises questions like: how should a multinational corporation deal with local laws, regulations, and customs including the local political constellation?
Read the texts below, and then answer the questions.
The first text is from a book on engineering ethics (6.3). It gives a brief description of the factual situation at the time of the accident. The second and third text were written by Indians, and try to give a sketch of the relevant aspects of the political situation in Bhopal and the rest of India (6.4, 6.5).

6.2. Questions

1. The Bhopal case is a case of the transfer of hazardous technology to a Non-Western country by a multinational from a Western country (in which the technology was developed). Discuss the question who should be held responsible for the Bhopal accident, and why. If you consider it helpful, you may use the following (non-exhaustive) list of *factors* and circumstances that played a role in the risk and in the accident:
- the safety of the production process including sensitivity to sabotage
- the toxicity of MIC
- the presence or absence of safety prescriptions, accident plans and the like
- the level of education of the personnel,
- the availability of educated personnel within India
- the distance between the plant and residential areas.

2. Ethicist Richard de George formulated the following questions:

"If Union Carbide were only a 40 percent owner, rather than a majority owner, would it have the same responsibility it presently has assumed? Is the solution to liability to accept less than a majority holding? Would a company act in a morally responsible way if it designed a plant with all the required safety features, and then turned the plant over to a local government or manager without any attempt to insure that the safety features continued to be implemented? National pride sometimes motivates a country to demand control of dangerous operations, using the local population, which has its own culture. Is it morally responsible of the host country to make such demands?" ("Corporate Moral Responsibility: The Bhopal Incident",
http://www.angelo.edu/events/university_symposium/1985/degeorge.htm, 16-7-2003)
Answer the following questions:
a) Was Union Carbide Int., given her majority holding, responsible for the (risk created by the) Bhopal plant even if it ran with Indian-only employees and management?
b) Would your answer be different if Union Carbide Int. would have had a minority holding in the Bhopal plant?
c) Is it justified in your view that UC Int. had to appear for an American Court, given that the accident took place in India in a plant run by Union Carbide India?
d) Was UC Int. responsible for the safety of the Bhopal plant? Given the circumstances under which the plant operated (e.g. all Indian employees), how should UC Int have fulfilled this responsibility? For example: by means of (extra) inspections, by altering the plant / process design, by exerting pressure on the city planners?

3. According to you, is it morally allowed for a corporation to exploit differences in customs and laws in order to maximise its profits? Such differences may include: differences in payment of workers; differences regarding human rights, and regarding health, safety and environmental laws. Which sort of differences can in your opinion be exploited in an ethically acceptable way, and which differences cannot? Defend your position.

6.3. The Union Carbide Plant at Bhopal

[From: *Ethics in engineering* by W. Martin and R. Schinzinger]

In retrospect it is clear that greater sensitivity to social factors was needed in transferring chemical technology to India (Shrivastava, 1987; Everest, 1985). By the late 1970s, Union Carbide had transformed its pesticide plant in Bhopal from a formulation plant (mixing chemicals to make pesticides) to a production plant (manufacturing chemical ingredients). It was fully aware of the hazards of the new technology it transferred. For years its West Virginia plant had made methyl isocyanate, the main toxin in two popular pesticides used in India and elsewhere. As a concentrated gas, methyl isocyanate burns any moist part of bodies with which it comes in contact, scalding throats and nasal passages, blinding eyes, and destroying lungs.

Yet, in designing the Bhopal plant Union Carbide did not transfer all the safety mechanisms available. For example, whereas computerized instruments controlled the safety systems and detected leaks at the West Virginia plant, Bhopal's safety controls were all manual and workers were asked to detect leaks with their eyes and noses.

The government of India required the Bhopal plant to be operated entirely by Indian workers. Hence Union Carbide at first took admirable we in training plant personnel, flying them to the West Virginia plant for intensive training. It also had teams of U.S. engineers make regular on-site safety inspections.

But in 1982 financial pressures led Union Carbide to relinquish its supervision of safety at the plant, even though it retained general financial and technical control. The last inspection by a team of U.S. engineers occurred that year, despite the fact that the team warned of many of the hazards that contributed to the disaster.

During the following 2 years safety practices eroded. One source of the erosion had to do with personnel: high turnover of employees, failure to properly train new employees, and low technical preparedness of the Indian labour pool. Workers handling pesticides, for example, learned more from personal experience than from study of safety manuals about the dangers of the pesticides. But even after suffering chest pains, vomiting, and other symptoms they would sometimes fail to wear safety gloves and masks because of high temperatures in the plant -the result of lack of air-conditioning.

The other source of eroding safety practices was the move away from U. S. standards (contrary to Carbide's written policies) toward lower Indian standards. By December of 1984 several extreme hazards, in addition to many smaller ones, were present.

First, the tanks storing the methyl isocyanate gas were overloaded. Carbide's manuals specified they were never to be filled to more than 60 percent of capacity; this was so that in emergencies the extra space could be used to dilute the gas. The tank which was to cause the problem was in fact more than 75 percent full.

Second, a stand-by tank that was supposed to be kept empty for use as an emergency dump tank already contained a large amount of the chemical.
Third, the tanks were supposed to be refrigerated to make the chemical less reactive if trouble should arise. But the refrigeration unit had been shut down 5 months before the accident as a cost-cutting measure, making tank temperatures 3 to 4 times what they should have been.

Six weeks before the catastrophe, production of methyl isocyanate had been suspended because of an oversupply of the pesticides it was used to make. Workers were engaged in routine plant maintenance. A relatively new worker had been instructed by a new supervisor to flush out some pipes and filters connected to the chemical storage tanks. Apparently the worker properly closed valves to isolate the tanks from the pipes and filters being washed, but he failed to insert the required safety disks to back up the valves in case they leaked. (He knew that valves leaked, but he did not check for leaks: "It was not my job." The safety disks were the responsibility of the maintenance department, and the position of second-shift supervisor had been eliminated.)

Two of four valves that should have been open to allow water flow were clogged. The resulting extra pressure was enough to force water to leak into a tank. For nearly 3 hours chemical reactions occurred, generating enormous pressure and heat in the tank.

By the time the workers noticed a gauge showing the mounting pressure and began to feel the sting of leaking gas, they found their main emergency procedures unavailable. The primary defence against gas leaks was a vent-gas scrubber designed to neutralize the gas. It was shut down (and was turned on too late to help), because it was assumed to be unnecessary during times when production was suspended.

The second line of defence was a flare tower that would burn off escaping gas missed by the scrubber. It was inoperable because a section of the pipe connecting it to the tank was being repaired. Finally, workers tried to minimize damage by spraying water 100 feet into the air. The gas, however, was escaping from a stack 120 feet high.

Within 2 hours most of the chemicals in the tank had escapes to form a deadly cloud over hundreds of thousands of people in Bhopal. As was common in India, desperately poor migrant labourers had become squatters –by the tens of thousands- in the vacant areas surrounding the plant. They had come with hopes of finding any form of employment, as well as to take advantage of whatever water and electricity available.

Virtually none of the squatters had been officially informed by Union Carbide or the Indian government of the danger posed by the chemicals being produced next door to them. (The only voice of caution was that of a concerned journalist, Rajukman Keswani, who had written articles on the dangers of the plant and had posted warnings: "Poison Gas. Thousands of Workers and Millions of Citizens are in Danger.") There had been no emergency drills, and there were no evacuation plans: the scope of the disaster was greatly increased because of total unpreparedness.

6.4. Union Carbide and the Indian government

[excerpt from: "The Union Carbide Disaster in Bhopal" by Satinath Sarangi, http://www.corpwatch.org/trac/feature/india/profiles/bhopal/original.html]

While the immediate and technical causes behind the disaster are significant for underscoring the primary liability of the Corporation and its officials, the economic and political context of the disaster are equally important. Union Carbide's pesticide factory in Bhopal was set up at a time when the Indian government was firmly resolved to carry out the Green Revolution in the country. Financed by industrialised countries and aggressively promoted by the Indian government this "revolution" sought to increase food production through mechanization of agriculture, construction of major dams for irrigation and introduction of chemical fertilizers and pesticides. In the two decades preceding the disaster in Bhopal, consumption of pesticides in the country had increased eight fold. As part of official policy for "special technology areas", Union Carbide Corporation was allowed to hold a majority 50.9 % ownership of Union Carbide India Limited far exceeding the limit set by the Foreign Exchange Regulation Act . In 1969, despite objections by conscientious officials, the Madhya Pradesh state government allowed Union Carbide to locate its inherently unsafe factory in the midst of populous settlements. The regional government ignored, and in fact promoted, the growth of settlements around the factory as increasing number of people were forced to leave their villages and come to the city in search of a livelihood. In the background of pro-Carbide official policy, the company rewarded officials and agencies who ensured its unregulated growth and expansion over the years. In the employment of senior managerial personnel in the factory, preference was given to the sons of bureaucrats who mattered, and regular contributions were made by the company to the ruling party coffers. Small wonder then that government agencies and officials responsible for monitoring and regulation chose to look the other way as the disaster was waiting to occur. In the immediate aftermath of the disaster as well as in the subsequent years the Indian government has been accused of protecting the interests of the multinational over those of the its own citizens.
There is sufficient evidence to show that government's figures of exposure induced mortality and morbidity are a gross underassessment of the damage that has actually been caused by the corporation. The infamous settlement of 1989 exposed the Indian government's pro-Carbide policy very clearly and possibly attracted more widespread criticism than it had drawn over its role in the disaster itself. Allegations were made that the political party in power had been gifted a large sum of money by the company and the seat offered at the International Court of Justice to the Chief Justice of Supreme Court of India who sanctified the settlement was not entirely based on merit. Government agencies involved in the assessment of injuries suffered by individual survivors produced ridiculously low figures that were in sharp contradiction to the data generated through epidemiological research. Official methods of injury assessment were found to be grossly unscientific and it was more than obvious that the damages have been tailored down to suit the paltry settlement amount. Decidedly the premature termination of monitoring and research activities by the government agency and the absence of documentation of long term consequences of the leaked gases will only help the multinational.

6.5. Bhopal Revisited: The View from Below

[by Amrita Basu, Bulletin of Concerned Asian Scholars, vol. 26, nos. 1-2, Jan.-June 1994, http://csf.colorado.edu/bcas/sample/bhopdoc.htm: introduction and conclusions]

Introduction

The night of 2-3 December 1994 will mark the tenth anniversary of the world's largest industrial disaster. Over the years the attention Bhopal has attracted has centred on the extended legal negotiations between the Union Carbide Corporation (UCC) and the Indian government. What is less known is that despite a settlement in 1989 and a review in 1991, the gas survivors continue to suffer untold misery. Indeed their lives are more insecure today than they were in 1984.

The forces that wreaked havoc on the lives of the poorest and most vulnerable segments of the population have displayed callousness throughout the nine years after the gas disaster. The Indian Council of Medical Research has still failed to devise appropriate treatment for the ailments of gas victims; UCC has refused to divulge information about the chemicals that could assist with diagnoses. According to one estimate, over 300,000 people continue to suffer from breathlessness, impaired vision, fatigue, body aches, loss of appetite, depression, and anxiety.[1] Moreover, the government has been slow and inept in distributing interim relief and has created little employment for those injured in the disaster.

The survivors were further victimized in 1990, when many were evicted from their homes to the outskirts of the city, where employment, food, and medical facilities are scarce. A large number of survivors once again sought shelter in the flimsy sheds of Bagh Farzat Afza, constructed years earlier as shelters for gas victims when the government engaged in its anti-encroachment drive. In December 1992, amidst a major "communal" riot in Bhopal, slum dwellers-many of whom are gas survivors-were among the most seriously affected groups.[2] More people returned to the sheds to escape the riot.

When the gas disaster occurred, attention focused on the irresponsibility of multinational corporations and their collusion with postcolonial governments.[3] I would argue that in the 1990s it has become increasingly clear that the suffering in Bhopal cannot be explained simply by the actions of multinational corporations in a neocolonial context. Such an explanation neglects the critical fact that the victims are predominantly Muslim. Events in the 1990s have highlighted the critical role of the state, not so much in pandering to multinational capital as in pandering to electoral considerations, which have been associated in turn with a communal stance. Focusing on the electoral compulsions underlying the state's actions and its antipoor, anti-Muslim bias reveals some important continuities between the events of 1984, 1991, and 1992.

In making this argument I do not mean to deny the influence on Indian politics of India's relationship to foreign capital. However, I would suggest that we not only devote greater attention to the role of the state, as scholars have already pointed out, but also to patterns of class and particularly communal stratification within India. UCC could locate its plant within a thriving urban metropolis like Bhopal, despite the government's knowledge that toxic chemicals were being produced there, not only because India needed access to foreign exchange and technology. Affluent Hindus lived in the elegant foot hills of Bhopal where they were relatively protected from the toxic fumes. By contrast the slums that mushroomed in the area adjoining the UCC plant were inhabited largely by poor Muslims.

To rectify the disproportionate attention that most accounts devote to the central government, I devote greater attention to the role of the state government. While the central government's role was critical until 1990-in authorizing a UCC plant in Bhopal, in its initial handling of the disaster, and in its subsequent negotiations with UCC-the role of the Madhya Pradesh (MP) state government has subsequently become critical. The right-wing Hindu nationalist Bharatiya Janata Party (BJP) that came to power in MP in 1990 has further victimized the Muslim gas survivors. Electoral considerations have prevented Congress, the major opposition party in Madhya Pradesh, from seriously challenging the BJP.

The vantage point of my account is that of the victims of successive crises in Bhopal. This "view from below" reveals continuities both in their sufferings and in the struggles they have waged. The Bhopal Gas Peedit Mahila Udyog Sangathana (the BGPMUS, the Organization of Bhopal Women-Worker Victims), an organization predominantly of Muslim women, has been at the forefront of struggles against UCC, the eviction of slum dwellers, and communal violence.

[…]

Conclusion

In the 1984-94 decade each tragedy Bhopal experienced built upon the previous one. Union Carbide took advantage of high levels of unemployment among Bhopal's population; the gas disaster then rendered this group poorer, sicker, and more rootless, which contributed in turn to the government's desire to rid the city of them. The riots in effect continued the government's anti-encroachment scheme by destroying thousands of huts that poor Muslim families were living in.

The logic of employing people to work for a plant that was known to produce deadly chemicals, "city beautification," and the riots reflect callousness toward poor, largely Muslim families. The Indian government seemed to assume that factory workers were fortunate to work for UCC, and thus did not take minimal precautions to prevent the remedy from killing the proverbial patient. The BJP government's use of gas-relief funds to demolish slums and provide urban facilities for the rich treated poor Muslim families as the dirt to be cleared. With the riot, there were no longer any safe places for Muslims in Bhopal.

The connections between each of these tragedies lies in the drift toward an electorally-and by implication communally-driven party system. While the BJP embraces an openly, violently anti-Muslim posture, Congress anticipated and continues to employ a paler version of the BJP's approach. The easiest way for political parties to make majoritarian appeals in India today is by exploiting religious and caste divisions. The Congress Party's appeals to Hindus at a time when its class-based appeals to the poor were becoming less effective laid the groundwork for the BJP's subsequent ascendance.

In the mid-1980s, when Arjun Singh liberally distributed land titles, Congress still relied heavily on minorities and the poor for electoral support. By the early 1990s it had become more dependent upon Hindu votes and refrained from risking unpopularity among urban middle-class Hindus by opposing the BJP's slum-demolition program. In 1992 Congress was determined to unseat the BJP government in MP and return to power at both the state and national levels. But if denunciations of the BJP brought Congress electoral dividends, it did nothing to stop the violence or help reorganize shattered communities: "Arjun Singh has his eyes on the chair in New Delhi," I was told by a senior bureaucrat who asked to remain anonymous, "so he is staying clear of affairs in Bhopal." Deep factional divisions within Congress also contributed to its ineffectiveness in responding to these crises.

Electoral considerations are equally important in explaining the BJP's changing stance. It moved from espousing the cause of gas victims when in opposition to underreporting their injuries when it came to power. Although the BJP's inaction during the riots might appear to undermine its electoral interests, N. Rajan of the National Mail concluded that the riots played a vital role in consolidating its disintegrating Hindu constituency. However, the midterm elections revealed a decline in the BJP's popularity in MP as a result of its poor performance in office. The 1993 elections, after a period in which communal violence had been absent, confirmed the decline in BJP fortunes.

The vacuum created by the inaction of the state and political parties has been filled by grass-roots activism. Muslim women, who had not participated in any form of organized political activity, have been at the forefront of struggles for employment, protest against the demolitions, and attempts to repair the damage caused by the riots.

In different ways the events of both 1984 and 1991 had devastating consequences for women. Numerous studies have shown that women's reproductive capacities were seriously damaged by the disaster. The public health minister of MP reported that 36 pregnant women spontaneously aborted and 6 gave birth to deformed babies just after the gas leak.[23] An Indian Council of Medical Research study in 1990 found a high rate-24 percent-of spontaneous abortion among gas-affected women. Subsequently the abortion rate has tended to be 7.5 percent for women who have been exposed to the gas as compared to 3 percent for unexposed groups.[24]

The gas disaster made it more difficult for women to mother and extended the demands associated with this role. Men were often unable to serve as the principal income earners in the family since their abilities to work full time had often been impaired. Given the imperative for women to earn wages, community restrictions that kept women homebound in the past began to slacken. It became acceptable for Muslim women to hold jobs and to support their families.

The catalyst to the formation of the BGPMUS was the state's tendency to alternate between concessions and repression.[25] Initially the government supported women's employment through its creation of sewing centres. Just as women had become reliant on this income, the government closed the centres down. The successful outcome of women's struggles led them to continue organizing. The government also decided to provide 836 widows with a monthly pension of 200 rupees ($12.00). When the more authoritarian BJP government came to power, women were already well organized. Given the high costs of transportation and the difficulties of travelling with young children from Gandhi Nagar to the city, many women had to give up their jobs. It is ironic that the BJP, which has decried the seclusion of Muslim women, was responsible for reprivatising women's work.

With the family endangered, women sought to defend family integrity and their own roles within the family. Muslim women's assertion of their identities as mothers represents a powerful response to Hindu communalism. The BJP is obsessed with questions of demographic balance between Hindu and Muslim communities. Both its slum-demolition program and the riots aim to reduce the Muslim population so that Hindus will enjoy unquestioned numerical and political supremacy. The BJP's fear that Muslim population growth rates would exceed those of Hindus particularly targets the fertility of Muslim women. Women's anguish at the damage to their reproductive capacities as a result of the disaster should be understood within this context. Similarly, women's attempt to maintain the integrity of their families and communities gains added urgency in the face of the BJP's attempt to create a Hindu state in which the choices for Muslims are exile, assimilation, or death. For women to assert themselves as individuals would pose no challenge to the BJP; to assert their identities as part of a visible, voluble, angry community of poor Muslim women offers the slender hope of cultural survival.

7. Sustainable development and the case of biofuel

In this chapter we focus on the notion of sustainable development and its relevance for the discussions on energy provision. At the heart of sustainable development lies the notion of justice between generations, alternatively known as *intergenerational* justice. In the following assignment, we try to interpret sustainable development in terms of obligations of the contemporaries towards future generations, with a special focus on biofuel. Biofuel is believed to be the promising substitute of fossil fuels in the future. As biofuel is a renewable energy resource, it obviously has serious advantages. However, there are also concerns such as the reliance of today's biofuel on agricultural crops such as corn and raises that bring about concerns of food scarcity, the more so because of rising food prices. Please read the text below and answer the following questions.

Questions

1. How can we approach the issue of energy provision and consumption as a matter of fairness between generations or intergenerational justice?
2. Is there such an intergenerational problem with respect to application of biofuel?
3. How can we relate concerns associated with the application of biofuel to the interests of future generations? Could you specify which aspects should be addressed? Is it relevant to distinguish between different crops and production systems?
4. Do you think that the current generation has an obligation to preserve biodiversity as it is at this moment? Please summarize your pro and con arguments before reaching any conclusion. Is your approach an anthropocentric one or do you see an intrinsic value in the nature?
5. Do you agree with the authors of this report that sustainability solely refers to the environmental issues and that social and economic issues should be dealt with separately? What does the Brundtland definition say on this matter?
6. Having discussed these issues on sustainable development and the (alleged) obligations to future generations, are you inclined to revise your opinion on which fuel cycle to choose, as discussed in Chapter 3 of this workbook?

Sustainable Biofuel: prospects and challenges[30]

7.1. Overview

Expansion in the use of biofuels for transport will entail both positive and negative environmental impacts. The extent and nature of these impacts will vary according to developments throughout the entire production chain from feedstock production, conversion and end use. If biofuels are to be genuinely sustainable, then the developments that offer the greatest environmental benefits will need to be given priority. However, there will also be trade-offs between the different impacts because some developments might offer benefits for one environmental issue while negatively impacting another. The potential impacts of widespread cultivation of biofuel crops and feedstock developments range across GHG emissions, changes in land use, water use and the impacts of increased nutrient and pesticide applications. Similarly, conversion into biofuels and subsequent end use of the fuel will also have wider environmental impacts including water usage and contamination and air quality. It is also important to consider the indirect environmental impacts that might arise as a result of the interactions between different land uses, such as land used for biofuels, food and material production. All these interactions will have impacts including those listed above; it will be important to ensure that impacts are not unfairly related to one use if they are also relevant to other uses. Ideally, all direct and indirect impacts need to be evaluated and applied in consistent assessment of biofuels. This would help to compare the overall benefits of different

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[30] The following text is drawn from Chapter 5 of the report 'Sustainable biofuel: prospects and challenges' with kind permission of the Royal Society. The complete report as issued in January 2008 could be found on: http://royalsociety.org/displaypagedoc.asp?id=28914

biofuels and indicate to what extent they are environmentally sustainable. The assessments would also help to identify practices and developments that offer the maximum benefits. Opportunities exist for how these issues can be assessed such as through use of tools like LCA. However, substantial knowledge and gaps in the data also exist in evaluation of impacts on biodiversity, water and eutrophication, so that tools such as LCA can at present only provide a partial picture of the real impacts of biofuels.

The analytical techniques and issues presented in this chapter will also have policy implications in the UK, EU and globally, such as on the UK RTFO and EU Biofuels Directive.

7.1.1.Sustainability of biofuels

Any assessment of the environmental impact of biofuels must also occur in the context of sustainability which incorporates other aspects, especially related economic and social issues. Inherently, the term 'sustainable' cannot be captured using a single simple metric. Instead, definitions tend to capture the concept by using diffuse but intuitive terms or a sub-set of quantifiable/semi-quantified targets such as the Millennium Development Goals (Brundtland 1987, UN 2007).

As with any new development, evaluating the economic and social impact of biofuels and their potential can be difficult. A robust economic assessment needs to incorporate changes such as removal or application of financial incentives, subsidies, taxes, and the emergence of new products and services. Without such assessments, investments which are very risky and wasteful may be made, and may not achieve the claimed economic benefits.

The development of biofuels also permanence of jobs), has both direct and indirect social impacts, including job creation (quality and social responsibility and social equity, including issues such as wealth distribution to rural communities. For example, the 'food versus fuel' debate is a serious issue as the rapidly increasing demand for biofuels can substantially distort global food markets (UN-Energy 2007). Whereas the rural poor in developing countries, who are mainly farmers or are involved with agricultural production and are likely to gain from increased agricultural commodity prices, the urban poor will be vulnerable to the price increases. Potential inequalities such as these have to be addressed within social sustainability and through more cautious use of policies to promote biofuels.

7.2. Life-cycle assessment

LCA is an established technique for evaluating the natural resource requirements and environmental impacts from the whole life cycle of a product or service (ISO 2006). In theory, LCA can be used to provide a complete evaluation of all the natural resource and environmental impact of a product or service. However, this requires a large amount of data on the life cycle of the product or service as well as the complete network of products and services used for its provision, use and, where relevant, re-use, recycling and eventual disposal. Although there are numerous software packages and supporting databases to accomplish this,(see Mortimer *et al* 2007) in practice, many LCA studies concentrate on the most prominent natural resource and environmental impacts of a given product or service.

In practice LCA usually focuses on land use, primary energy and GHG emissions, and it provides a highly effective means of estimating total GHG emissions and energy resource depletion associated with the production and utilisation of biofuels. These estimates are calculated relative to the conventional oil-based transport fuels that biofuels potentially replace. Some combinations of options for producing biofuels could result in only small net GHG savings, and in the worst circumstances, total GHG emissions could be higher than those of fossil-based petrol and diesel. Conversely, if favourable combinations of options are chosen, then biofuels can be truly 'carbon neutral' (zero total GHG emissions or 100% net savings) or perhaps even 'carbon negative' (potential GHG emissions savings exceed those of fossil-based diesel and petrol) (see Larson 2005 and references in Table 5.2).Therefore, deriving such estimates will mean that LCA can be used as a tool to help decide on the combinations of options for producing and using biofuels that result in the largest reductions in GHG emissions. As biofuels and feedstocks can be imported, the technical and geographical scope will affect LCA results, which makes it important to ensure that such differences are also incorporated into assessments.

Other potentially important issues that have received less attention in LCAs include water consumption, eutrophication, biodiversity and air pollution (Rowe *et al* 2007). Where data on these other impacts are available, they need to be incorporated into LCA. In the absence of such data, these wider impacts also need to be analysed using techniques such as SEA and EIA. These assessments are enshrined by EU directives and provide a more qualitative assessment of the wider impacts of products and services, such as biofuels (EU 1997, 2001). The assessments are especially important where quantitative data do not exist on specific environmental impacts. These assessments do not replace LCA but can add balance by providing a more holistic picture of environmental impacts. Decision makers need to ensure that assessments of biofuels are based on both quantitative LCA and qualitative assessments. Decisions on the choice of biofuels and production processes must also ensure that the influence of quantitative and qualitative data is balanced objectively so far as possible.

7.3. Biofuels and greenhouse gas emissions

Greenhouse gases, such as methane, carbon dioxide and nitrous oxide (N_2O), are emitted along the entire supply chain and are affected by various practices and processes, including fertilizer use, agronomy, harvesting, conversion and distribution. In addition, plants also emit volatile organic compounds (VOCs) such as isoprene, which not only affect air quality, but in the presence of NO_x can lead to the formation of the GHG ozone (see Section 5.7.1) (Arneth *et al* 2007). LCA can incorporate some of the main sources of GHG emissions into calculations (see Section 5.3). However, as discussed in Chapter 2 there is a need for substantial research to provide better assessments of land use change, soil carbon and N_2O emissions and how these might be reduced.

7.3.1. Soil carbon and carbon sinks

Chapter 2 highlighted that the CO_2 emissions from converting land types, particularly those that are large carbon sinks need to be evaluated. Studies estimate that the net land carbon sink, including soils and vegetation, is approximately 1.5 gigatonnes of carbon per year (GtC/yr), and takes up some 20% of current human CO_2 emissions (Royal Society 2001). However there are uncertainties in quantifying the size of land carbon sinks at a local scale that requires research (Royal Society 2001). Globally, peatlands contain about 528 Gt of carbon, of which 42000 Mt is contained in forested tropical peatlands of SE Asia (Hooijer *et al* 2006). Drainage of the peatlands in SE Asia can lead to emissions of CO_2 of up to 100 t/ha/yr or 3 kg/m^2/day, but if the land is subsequently burnt this figure could double or treble. Between 1997 and 2006, CO_2 emissions from the drainage and burning of peatlands in SE Asia averaged about 2000 Mt/yr, equivalent to 8% of global emissions from fossil fuel burning (Hooijer *et al* 2006). These emissions of soil carbon apply regardless of the cause of the land change to the cultivation of crops, whether for food or fuel applications. The causes of peatland degradation are multifold including deforestation by logging, and drainage and burning for development of timber plantations, agriculture and oil palm (some of which is used for biodiesel production in Europe). Thus the cause of this problem cannot solely be attributed to biofuel demand as other industries are intricately involved.

7.3.2. Emissions of N_2O from biofuels

The GHG nitrous oxide (N_2O) has a global warming potential 296 times greater than CO_2 (IPCC 2007a). It is produced in the soil from nitrogenous fertilisers and from natural mineralization of nitrogen, by the parallel processes of bacterial nitrification and denitrification. The largest single global source of atmospheric N_2O today is use of industrial fertilisers[31] for agricultural production.

[31] Using fertiliser can also result in eutrophication of water courses, which is discussed in Section 5.7.

To maintain high rates of annual production, arable crops are generally fertilised at rates of up to 350 kg/ha/yr of nitrogen. If new land is brought into cultivation for biofuels, as seems necessary to meet policy requirements, after the first year or two sustained production will require regular fertiliser applications, which in turn will lead to an increase in emissions of N_2O. The IPCC estimates that 1% of added nitrogen is returned to the atmosphere through activities that result in the mineralisation of soil organic matter (IPCC 2006). However, a recent paper by Crutzen *et al* (2007), which considers N_2O release from rivers, estuaries and coastal zones, animal husbandry and the atmospheric deposition of ammonia and NO_x, highlights that it is more likely that the amount of nitrogen returned to the atmosphere as N_2O is in the range 3–5%. Using this larger range of N_2O emissions could significantly reduce the currently assumed GHG emission gains from replacing conventional fossils fuels with biofuels such as biodiesel from rapeseed and bioethanol from maize.

There is a need to improve our understanding of the scientific basis for N_2O release from different biofuel crop production systems and land types. This also needs to be coupled with better understanding of the nitrogen cycle and the interactions of these systems. Such improved knowledge would help when comparing which plants and production systems produce lower N_2O emissions and, in turn, would help decide upon those systems that provide the best GHG savings. Feedstock developments can help in this regard (see Chapter 2). Investigating the potential of 'win-win' opportunities such a wastewater remediation and crops growth could be useful here (see section 2.3).

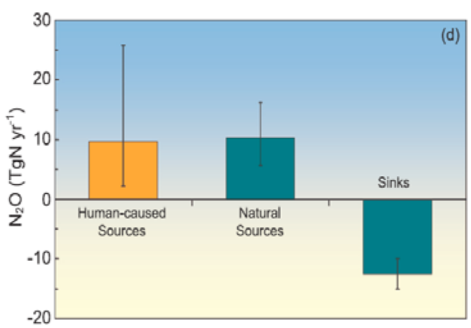

Figure 5.1. Estimate of human and natural induced increase in atmospheric N_2O emissions. Note: human sources of N_2O include the transformation of fertiliser nitrogen into N_2O and its subsequent emission from agricultural soils, biomass burning, cattle and some industrial activities. Although understanding of the human impact has improved, the data and error bars highlight that there is still a need to improve quantification of human sources of N_2O. (Adapted from IPCC (2007a)

7.4. Land use

There are many competing demands for land: to grow food, for conservation, urban development and recreation. The larger the amount of productive land diverted away from food production to grow biofuel crops, the larger the implications for food availability and prices. Thus there is considerable interest in the use of less productive land for cultivation of biofuel feedstock, such as marginal lands. Also, opportunities for gaining the maximum use from the crops grown and combining food and non-food applications need to be developed. This development is likely to involve providing incentives for the growers of the feedstocks and should involve consideration of the full range of parameters, including environmental and socio-economic impacts. As discussed above, the use of LCA should help to provide an objective assessment of the relative merits of different feedstocks and the production systems. There are however limitations that need to be overcome and other factors involved in land use assessment also need to be accounted for such as land quality (including nutrient and water content) and soil carbon changes.

7.4.1.How much land to meet UK policy targets?

Estimates for the amount of UK land that will be required to produce enough biofuels to replace 5% (by volume, as proposed by the RTFO) of current usage of oil-based transport fuel vary widely. Calculating such a figure can be difficult as it depends on a range of interacting factors that will have implications on how the UK meets its policy targets. These include among others:

- the type or mix of biofuels produced
- the feedstock from which the biofuels are derived, including their energy content and yield per hectare
- the cultivation practices,
- the type of conversion process
- the sources of heat and electricity used in the conversion of the biomass feedstock into finished biofuel
- the use of by-products and the allocation procedures applied to their evaluation.

Figure 5.2 (taken from Woods & Bauen 2003) shows the range can be anywhere between about 10% of UK arable land (for ethanol from sugar beet) up to about 45% land use for wheat straw to ethanol; of the UK's total land area of 24.25 Mha, 6 Mha is arable land and 2.4 Mha is forest (Defra 2005). These figures do not take into account the net energy balance of the system, so although some of the feedstocks use less land, the overall energy balance can be poor. In reality, a range of crops will probably be used to meet biofuels policy directives, so the actual land use figure will also depend on the proportions of this mix. In addition, technological developments along the supply chain will also impact on land use. For example, improving crop yield per hectare and improving conversion efficiency will provide a greater final yield of biofuel, which will use less land to meet policy directives. However, these estimates make it clear that there is no realistic prospect of the UK becoming self-sufficient in biofuels for transport for anything more than low replacement levels of use. Finally economic and social factors will also have an impact on how much land is used, including the level of importation of biofuels to meet policy targets as well as other land-use objectives for rural communities.

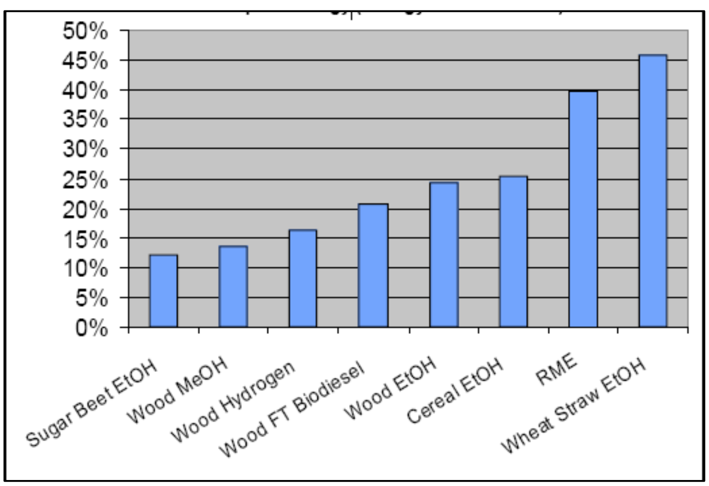

Figure 5.2. Percentage of UK arable land area needed to supply 5% of energy demand by transport in 2001, on an energy content basis. Note: These figures show the mid-point for each option and do not show the possible range, which would depend on factors such as the cultivation practice, crop yield, conversion and process efficiency. (Source: Woods & Bauen 2003)

7.4.2. How to compare land use

Land use can be compared in a variety of ways, most of which are based on calculating the overall energy balance. The most convenient way to compare the land used by different biofuels and other sources of biomass is in terms of delivered energy per unit land area (in units of millions of joules per hectare per year (MJ/ha/yr)). Delivered energy is the energy contained in fuels and electricity which consumers access for their subsequent use. It is derived from primary energy[32], which is a measure of the amount of energy contained in depletable natural resources including fossil fuels and nuclear fuel. Delivered energy can be converted into 'useful energy', which is the energy needed as heating, cooling, light, motive power, etc. A clear distinction must be made between primary energy and other forms of energy. These different forms of energy are not interchangeable and cannot be equated with each other. As a consequence of inevitable inefficiencies and losses, a greater amount of primary energy is needed to provide a given amount of delivered energy, which in turn is greater than the amount of useful energy that can eventually be supplied. Often in the assessment of energy technologies, deceptively simple indicators can be derived such as the ratio of primary energy input to delivered energy output. Given the definition of primary energy, this ratio is greater than one for energy technologies based entirely depletable resources such as fossil and nuclear fuels. For renewable energy technologies, including biofuels, it can be less than one (see Table 5.2).

Tables 5.1a to c provide average estimates of delivered energy available from various UK feedstocks under particular conditions and specified assumptions. These estimates do not account for delivered energy required in the provision and conversion of the feedstock into biofuels; this can be achieved by evaluating these processes using estimates of the primary energy needed. It should be noted that only forestry residues are included in Table 5.1b, c, and that no quantification has been made of the amount of delivered energy that could be gained currently available forestry timber, which potentially could provide significant benefits in terms of delivered energy. The tables show that certain combinations of options can result in real efficiency gains in land use.

Table 5.1a illustrates the estimated delivered energy available from specific liquid biofuels that could be produced in the UK from major feedstocks. Two types of estimate are presented: the first only considers the delivered energy available from the liquid biofuel, as the main product of each process under investigation; the second takes into account all the delivered energy that could be available from the main product and all co-products that could be used as fuels, on the assumption that these co-products would be converted into heat by conventional combustion. The estimates will change by adopting other conversion technologies, such as gasification or pyrolysis, or if the co-products were used in electricity generation or Combined Heat and Power (CHP) production. The delivered energy available also varies considerably depending on whether feedstock is regarded as a source of liquid biofuels only or as an integrated source of delivered energy. The estimates in both Table 5.1b, c would also alter if potentially more efficient technologies were applied or if CHP generation was adopted. Overall these tables imply several key points:

- That more efficient land use is possible by using existing feedstock and by using co-products more efficiently. For example, using wheat grain to produce bioethanol and the straw to generate process heat and electricity results in delivered energy that is much greater than for other combinations shown in Table 5.1a.
- Feedstock converted into liquid biofuels can be a more efficient use of land than using feedstock to generate electricity, and in some circumstances, it can also be more efficient than for heat generation. For example, bioethanol produced from wheat grain with the straw used for heat is more efficient than all electricity production processes and heat production processes (except for heat from miscanthus pellets).
- Policies supporting biofuel development need to incentivise those processes that are the most efficient use of land.

[32] In this definition, primary energy does not include renewable energy (such as biomass energy).

Table 5.1. Estimated delivered energy available from liquid biofuels and energy available from electricity and heat from lignocellulose feedstock. Notes: (1) Figures do not account for the amount of energy required for the provision and conversion of the feedstock. (2) b, c do not include lignocellulose from forestry timber, which would provide a much greater delivered energy value than that provided by using residues. (3) Other lignocellulose feedstocks, such as switchgrass, are not included. (4) b, c are based on energy from combustion: more efficient conversion technologies would increase the delivered energy available.

(a) Estimated delivered energy available from liquid biofuels in the UK

Liquid biofuel and process	**Unit delivered energy available[(a)] (MJ/ha/yr)**
Biodiesel only from oilseed rape (plant oil)[(b)(n)]	40,335
Biodiesel and co-products from oilseed rape (plant oil for fuel[(b)] and rest of plant for heat[(c)(m)]) [(n)]	99,849
Bioethanol only from wheat grain (starch)[(d)(o)]	67,085
Bioethanol and co-products from wheat (wheat grain (starch)[(d)] for fuel and wheat straw for heat[(e)(m)])[(o)]	148,825
Bioethanol only from sugar beet (sugar)[(f)(o)]	117,105

(b) Estimated delivered energy available as electricity from lignocellulose feedstocks in the UK

Feedstock and method of combustion	**Unit delivered electricity available (MJ/ha/yr)**
Forestry residue pellets for co-firing[(g)(k)(p)]	2,146
Forestry residue chips for dedicated combustion power plant[(g)(l)(p)]	2,152
Forestry timber	Not available
Straw for dedicated combustion power plant[(h)(l)(p)]	11,803
Short rotation coppice pellets for co-firing[(i)(k)(p)]	32,087
Short rotation coppice chips for dedicated combustion power plant[(i)(l)(p)]	36,178
Miscanthus for dedicated combustion power plant[(j)(l)(p)]	65,999
Miscanthus for co-firing[(j)(k)(p)]	90,549

c) Estimated delivered energy available as heat from lignocellulose feedstocks in the UK

Feedstock and method of combustion	**Unit delivered heat available (MJ/ha/yr)**
Forestry residue pellets for combustion[(g)(m)(p)]	4,903
Forestry residue chips for combustion[(g)(m)(p)]	5,029
Forestry timber	Not available
Straw for combustion[(h)(m)(p)]	37,768

Short rotation coppice pellets for combustion(i)(m)(p)	73,339
Short rotation coppice chips for combustion(i)(m)(p)	73,472
Miscanthus pellets for combustion(j)(m)(p)	206,967

(a) Delivered energy measured in terms of net calorific value (lower heating value (LHV)).
(b) Assuming oilseed yield of 3.1 t/ha/yr at 15% moisture content.
(c) Combustion of rape straw assuming a yield of 2.81 t/ha/yr, rape meal assuming an effective yield of 1.70 t/ha/yr and glycerine assuming a yield of 0.11 t/ha/yr.
(d) Assuming wheat grain yield of 8.6 t/ha/yr at 20% moisture content.
(e) Combustion of wheat straw with a yield of 3.78 t/ha/yr and 15% moisture content, and distillers' dark grains and solubles (DDGS) with an effective yield of 2.87 t/ha/yr.
(f) Assuming sugar beet yield of 52.1 t/ha/yr.
(g) Assuming forestry residues yield of 0.50 t/ha/yr at 25% moisture content
(h) Assuming straw yield of 3.78 t/ha/yr at 15% moisture content.
(i) Assuming short rotation coppice yield of 12.1 t/ha/yr at 50% moisture content.
(j) Assuming miscanthus yield of 28 t/ha/yr at 50% moisture content.
(k) Co-firing in a coal-fired power plant with a thermal efficiency of 35%.
(l) Combustion in a dedicated power plant with a thermal efficiency of 25%.
(m) Combustion in a heating plant with a thermal efficiency of 80%.
(n) Mortimer *et al* (2003a).
(o) Mortimer *et al* (2004).
(p) Elsayed *et al* (2003).

7.4.3. Comparison of energy resource depletion and GHG emissions savings

The evaluation of total GHG emissions and the ratios of primary energy inputs to delivered energy outputs associated with the production and utilisation of biofuels needs to be set in context of the fossil-based transport fuels that they are intended to replace. This helps to compare the relative benefits of different biofuels and is done by comparing the GHG emissions and energy ratios from biofuels with those of petrol and diesel. The baselines adopted here are represented by the estimates summarised in Table 5.2. Total GHG emission estimates in Table 5.2 are based on IPCC (2001) values of global warming potential and assume that all net savings exceeding 100% are due to credits from the displacement of a UK mix of electricity generation. There are significant differences in total GHG emissions and net savings for some biofuels. Whilst net savings can be low (less than 50%) if unfavourable combinations of production options are chosen, it is also possible to achieve very high net savings. Indeed, it is even possible to obtain net savings exceeding 100%. This is due to the avoided GHG emissions when surplus electricity is generated from by-products. These calculations depend on the factors outlined in Section 5.5.1.

By way of illustration, some typical estimates of total GHG emissions and net savings for biodiesel production from plant oils (oilseed rape), bioethanol production from sugar (sugar beet) and bioethanol production from starch (wheat grain) are presented in Table 5.2. Apart from a brief summary of the production details, the major assumptions incorporated into these estimates are recorded in the attached notes (a–r). To provide meaningful comparative estimates, published studies have been used; these have sufficient transparency to enable basic assumptions to be applied consistently. In particular, such consistency applies to the assumed values of global warming potentials for CH_4 and N_2O, GHG emission factors, especially for the manufacture of nitrogen fertiliser, the production of natural gas and the generation of electricity, N_2O emissions from soils, and the allocation procedures for by-products.

Table 5.2. Comparison of energy and greenhouse gas savings for different crops and production systems.

Feedstock	Co-product use	Agriculture practice	Process inputs: heat and power	Energy: Ratio of primary energy inputs: delivered energy output MJ / MJ net	Energy: Net Primary energy savings %	Greenhouse gas emissions: Total greenhouse gas emissions (j) g CO_2eq. / MJ net	Greenhouse gas emissions: Net greenhouse gas emissions savings % (j)
Conventional fuels							
Ultra-low-sulphur diesel (a)(l)(m)				1.26		87.6	
Unleaded petrol (b)(l)(o)				1.19		81.5	
Bioethanol							
Starch (wheat grain (d)(o)	Distillers' dark grains and solubles (DDGS) use as animal feed	Conventional (e)(q)	Natural gas-fired process heat, grid electricity	0.64	46	63.5	22
	DDGS use as animal feed	Conventional (e)(q)	Natural gas-fired process CHP	0.60	59	52.1	36
	DDGS use as animal feed	Conventional (e)(q)	Straw-fired process CHP	−0.07	106 (k)	36.7	55
	DDGS use as co-firing (p)	Conventional (e)(q)	Straw/coal-fired process CHP	−0.63	153 (k)	11.6	86
Sugar (Sugar beet)(o)	Beet pulp used as animal feed	Conventional (q)	Natural gas-fired process heat, grid electricity	0.83	30	48.6	40
	Beet pulp used as animal feed	Conventional (q)	Natural gas-fired process CHP	0.68	43	41.1	50
	Beet pulp used as animal feed	Conventional (q)	Straw fired process CHP	−0.52	144 (k)	-93.4	215 (k)
Biodiesel							
Plant oils (oilseed rape)	Rape meal used as animal feed (f)(m)	Conventional (h)(q)	Natural gas-fired process heat, grid electricity	0.44	65	46.3	47
	Rape meal used as animal feed (g)(m)	Low-nitrogen (i)(q)	Natural gas-fired process heat, grid electricity	0.33	74	29.9	66
	Rape meal used as animal feed and co-firing (g)(n)	Low-nitrogen (i)(q)	Rape straw/coal-fired process CHP	0.21	83	26.2	70
	Rape meal used only for co-firing (g)(n)(r)	Low-nitrogen (i)(q)	Rape straw/coal-fired process CHP	−0.35	128 (k)	-5.6	106 (k)

(a) Ultra low sulphur diesel produced in the UK with a net calorific value of 42.38 MJ/kg.
(b) Unleaded petrol produced in the UK with a net calorific value of 43.99 MJ/kg.
(c) 103 kg N/ha/yr application during cultivation and a sugar beet yield of 52.1 t/ha/yr Average EU-15 soil emissions of 2.79 kg N_2O/ha/yr for sugar beet cultivation.
(d) Wheat yield of 8.60 t/ha/yr at 20% moisture content.
(e) 185 kg N/ha/yr application during cultivation. Average EU-15 soil emissions of 2.23 kg N_2O/ha.a for wheat cultivation.
(f) Oilseed rape yield of 3.07 t/ha/yr at 15% moisture content.
(g) Oilseed rape yield of 2.92 t/ha/yr at 15% moisture content.
(h) 196 kg N/ha/yr application during cultivation. Average EU-15 soil emissions of 3.12 kg N_2O/ha/yr for oilseed rape cultivation.
(i) 81 kg N/ha/yr application during cultivation. Average EU-15 soil emissions of 3.12 kg N_2O/ha/yr for oilseed rape cultivation.
(j) Assumed Global Warming Potentials of 23 kg eq. CO_2/kg CH_4 and 296 kg eq. CO_2/kg N_2O (IPCC 2001).
(k) Net savings exceed 100% due to credits from the displacement of a UK mix of electricity generation.
(l) Excluding vehicle combustion CH_4 and N_2O emissions.
(m) Mortimer *et al* 2003a.
(n) Mortimer *et al* 2003b.
(o) Mortimer *et al* 2004.
(p) Punter *et al* 2003.
(q) Edwards *et al* 2006.
(r) Mortimer & Elsayed 2006.

Overall Table 5.2 makes the following key points:

- There is a great deal of variation in greenhouse gas emissions savings between different biofuels. Savings depend on how co-products are used, the type of agriculture and how the conversion processes are powered.
- A lot of potential exists to improve the efficiencies of existing feedstocks including wheat, sugar beet and oilseed rape. For example for bioethanol production from sugar beet, if the beet pulp is used as animal feed, under conventional agriculture and there is a straw fired CHP process, then net greenhouse gas savings can amount to 215% compared to petrol.
- Policies are required that incentivise combinations of production processes that deliver the greatest greenhouse gas savings.

7.5. Water consumption

In some locations, including the UK, the availability of water can be a fundamental consideration for the practical cultivation of crops for biofuel production. Water is required through the entire biofuel supply chain, and is best documented for feedstock production. Distribution of water resources varies greatly according to location and time. Globally, pressures on water supply are increasing from a growing population, per capita usage and the impacts of climate change (UNESCO-WWAP 2006). Consequently, water for all uses is becoming scarce. Developments in the agricultural sector for food and non-food crops will have important implications for water usage and availability. Increased usage of biofuels will raise demand for water, which could, in turn, negatively impact on water availability for other uses. These issues require careful consideration by decision-makers when deciding upon the potential role for biofuels and in any sustainability assessments of biofuels.

Although there are some data available about water use efficiencies of crops, which can be placed into LCA calculations, water requirements through the rest of the biofuel supply chain (processing and end use) are unknown. This is a generic issue that not only applies to biofuels but also to other industries such as conventional oil and gas and food. There is a clear need for R&D to establish water use requirements across the entire biofuel production chain.

Growing any crop will require water and specific crops will need more than others but there is not an extensive database of this information, and some of data does not always account for differences in the factors that impact water use efficiency (WUE). WUE depends on several factors including precipitation, evaporation, transpiration, which in turn, are dependent on climatic variables, including elevated CO_2 levels, solar radiation absorption and windspeed (see McNaughton & Jarvis 1991 and FACE CO_2 experiments - REF). There is a need to assess these factors for different crops at different locations. It must also be noted that even if crops have high WUE, their impact on water availability is a separate issue that will also need to be evaluated. Water availability will also affected by interactions and competition with other crops and land use change. The likely choice and dynamic changes in crop production and the species/varieties chosen for biofuels will inevitably have an effect on the flows of water through the landscape. Hydrological studies, such as those being funded by Natural Environment Research Council and the Centre for Ecology and Hydrology, will need to focus on the extent to which roots from new crops extract water from the ground and therefore calculate any resulting impact on water availability. Such studies could also help inform agricultural practices so crops can be planted at times of the year where they will have a lower impact on the ground water resource. Water catchment management will also be of importance here to ensure the resource is secured.

We recommend the development of datasets to account for water use efficiency across the entire biofuel supply chain. These datasets need to account for variations between crops and the conditions at specific locations that affect water use. In addition, the results from hydrological studies will also need to be integrated into these datasets to assess the overall impacts of biofuel use on water availability. LCA calculations could provide a useful way of assessing many of these issues.

7.6. Biodiversity

Biodiversity provides an important role in ecosystem functioning and the provision of services that are essential for human wellbeing (for example human health, food etc) (MEA 2005). However, over the past few centuries human activity has resulted in fundamental and irreversible losses of biodiversity. This loss is accelerating with changes most rapid over the past 50 years (MEA 2005). Globally, habitat conversion for agriculture and forestry has been a major driver of this loss; for example, more land was converted to cropland between 1950 and 1980 than between 1700 and 1850 (MEA 2005). The situation is different in the UK because of the long history of humans changing the natural environment through agriculture and forestry, which has resulted in the production of 'semi-natural' managed landscapes, some of which are nevertheless highly valued for their amenity value.

Chapter 2 highlighted that any form of agriculture can pose risks to biodiversity and there are opportunities to improve biodiversity by using specific crops and land management systems. As with any new agro-ecosystem, growing a biofuel crop will alter local habitats and resources in a way that will affect native species distribution and abundance. These effects will depend on the crop, its density, duration and distribution on the landscape, and any regular inputs, including water and agrochemicals. Given the range of potential crops, from trees to dense grasses, impacts to biodiversity will vary.

Several other impacts also need to be evaluated both within the UK and also globally. These include impacts such as those arising from direct effect of change in land use; from just changing the crops being grown in an agricultural landscape, to going from a diverse crop system to monocultures, through to large-scale conversion of biodiverse systems, such as peatlands and tropical forest. If using UK set-aside land to grow biofuel crops, then consideration any resulting impacts on biodiversity will also need to be evaluated because some of these areas are very biodiverse relative to farmland (Critchley & Fowbert 2000).

As the cultivation of new crops intensifies then new impacts, such as pests and diseases, will also occur and will need to be addressed. There is a risk that pests and diseases could lead to increased use of pesticides/herbicides. This in turn could lead to changes in pest and disease resistance and subsequent impacts on crop yield, as was experienced in the 20th Century with oilseed crops in the UK.

The characteristics of biofuel crops may also be important in determining their potential impact on biodiversity. Characteristics that make them appealing for crop use, such as fast/vegetative growth and high yield, may also enable them to become invasive under the right environmental conditions. Introducing new species into an area can raise the risk of infestation by new pathogens and pests. If crops spread into surrounding habitats, particularly natural ecosystems they may also displace local biodiversity and/or disrupt ecosystem processes, including for example water and nutrient cycles. There is a precedent for introduced, fast growing tree crops becoming invasive in this way, particularly in the warmer regions, such as *Eucalyptus*. There is also some evidence that grasses such as sweet sorghum, giant reed and reed canary grass are invasive in specific environments in the USA (Raghu *et al* 2006). In addition, miscanthus and switchgrass are being assessed for invasiveness in the USA. Miscanthus species that exhibit vegetative propagation, an ability to resprout from below ground, efficient photosynthetic mechanisms and rapid growth rates could be invasive. Switchgrass, a seed-producing species, shares many of these invasive traits.

Any evaluation of these risks needs to be balanced with the potential benefits to biodiversity. There is evidence showing that biodiversity could benefit under certain circumstances (Anderson & Fergusson 2006; Rowe *et al* 2007). Large-scale SRC willow can provide benefits for some bird species, butterflies and flowering plants. The impacts of perennial grasses are less well known and require further research. However, in mixed compositions some perennial grasses may also provide some wildlife benefits compared with conventional, intensively managed farmland. It will be important to identify and support such 'win–win' situations.

It is clear that the overall risks and benefits for biodiversity need to be appropriately evaluated for any potential bioenergy crop. We recommend that potential bioenergy crops be evaluated by using a risk assessment framework that covers the following:

- the full life-cycle of biofuel production
- the invasiveness potential of the crop
- takes into account the potential interactive effects of the biofuel crop with other pressures in the area (such as for example, drought stress)
- the impacts to ecosystems
- changes in these risks under a future climate.

Application of existing tools to measure impacts of agricultural practices on key biodiversity indicators may be useful for developing methods to assess biodiversity impacts on pilot plantings. The non-native species risk assessment methodology, developed for Defra, for assessing the environmental threats posed by introduced species is one such example; there are others. In addition, current and ongoing UK projects on biodiversity impacts of energy crops, such as that underway on willows in the Rural Economy and Land Use (RELU) programme of ESRC, NERC and BBSRC, will help develop relevant methodology. Risk assessments of crops will also need to occur with ongoing monitoring of locations where crops are grown to help provide an evidence base for future decisions. This would help to ensure that any unintended impacts (positive and negative) can be identified and appropriate actions can be targeted to deal with such impacts. Given that biofuel feedstocks will be produced globally, appropriate measures need to be taken to ensure that barriers to undertaking risk assessments, such as poor knowledge of biodiversity and lack of access to monitoring tools, are addressed. Addressing biodiversity in LCA is constrained by the lack of data as crops and regions that are growing feedstocks have not yet been assessed for their impacts on biodiversity. Establishing this knowledge base would also help to address biodiversity impacts in LCA calculations.