An Electrical Storm on the Horizon: Can Technology Stimulate Reasoned Debate on Waste Containment?

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About 11:00 a.m., James Mason, who held extension positions both with agriculture and environmental engineering at Oklahoma State University, got the call he had been dreading for months. "James, this is George Smith. I hate to break it to you this way, but the rabid wolves at *The Daily Oklahoman* have gotten wind of the abatement project the state is contracting near Mangum."

"Oh, great. Has the story hit the presses yet?"

With a heavy sigh George, the state engineer on the Oklahoma power plant decontamination project, replied, "Well, James, the news isn't as bad as that, but the reporter is Misty Dorfmann, who came out of one of those eastern journalism schools to reform 'the worst newspaper in America' (Selcraig 1999), and she is definitely angling for a Pulitzer. Luckily she was given my name to check the article for technical accuracy. They are going to run it early next week, which gives us about five days to get something going. There is no way to hold up on this any longer—she is really pushing it hard, and if I try to delay it she's only going to see a cover-up where there isn't one. The one bright side is that Misty seems pretty reasonable and wants to do a long series of follow-up articles, which, incidentally, are what would be required for the Pulitzer...."

"Five days.... That isn't much time to get a plan together—certainly not at the rate things move in this state. Any luck getting funds to do this study from your office, George?"

"Not a chance! You know that the budget is tight with the tax cuts. The you-know-what is going to hit the fan on this and it is going to be our necks in the noose. We've been pushing for funds for this groundwater study for nearly a decade, only to be stymied at every turn. Those gypsum karsts are porous as anything and contamination of the Elm Fork of the Red River is a potential problem. But with the big power scares out west a few years ago and the number of power plants going up in the state, this decontamination facility was pushed at the highest levels. If data don't exist now, it is going to get even harder for my office to get funds to prove this is a potential problem."

"That's politics for you," James complained. "So what we need is a way to *prove* one way or the other if complex organic molecules can permeate into the ground water and get into the watershed. We both know General Toxidyne should have lined those ponds, but your boss caved in on that under pressure from higher up. But if we prove the ponds are leaking, you will almost certainly lose your job and I'll probably get transferred from Stillwater to some hole of an office out in the panhandle...."

"Yeah, it really is a problem, isn't it. Too bad no environmental group can do this type of study. They just don't have the money to run the number of samples that would be required."

There was a long pause as something tickled the back of James' mind. The thought almost surfaced until George interrupted, "James, are you there?"

"Yeah, George, just trying to think of a solution. Look, I have to give a lecture in Professor Sanderson's class. I'll call you back tomorrow. I need some time to think of what to do."

"You and me both, James, you and me both."

The problem facing James and George was a multifaceted one. A large number of power plants were under construction in Oklahoma, where citizen protest was much smaller than many other more highly populated states. While the economic benefits were potentially great, especially to underdeveloped areas, there was a host of other problems to face with the construction of power plants. The most visible of these was their potential impact on the environment. Fortunately the use of scrubbers to clean the air from combustion byproducts eliminated some toxic byproducts, but many of them were trapped and had to be disposed of in other ways. While much of the public's ire was over coal-fired power plants [2], nearly all types of plants came under scrutiny.

Various technologies were used for control emission of harmful combustion byproducts to clean, or "scrub," the air. The premise of scrubbing is straightforward: byproducts of combustion include harmful compounds such as hydrogen sulfide, sulfur oxides, and nitrogen oxides. Scrubbers contain catalysts or chemicals that adsorb and break down such pollutants. Of all the plants that produce electricity by combustion, those that burn natural gas produce the least toxic byproducts. Coal and burning trash produce more potentially toxic byproducts, including carbon monoxide; highly toxic nitrogen oxides; gases which can contribute to acid rain such as sulfur dioxide and hydrogen chloride; ordinary smoke and soot, known as particulates, which can contain dioxins and solid metals; and, perhaps worst of all, mercury.

Various techniques were available to reduce air pollution. High furnace temperature and proper air control prevent the formation of dioxins and carbon monoxide, which are created when organic matter does not burn completely. Temperature control also limits the formation of nitrogen oxides. Nitrogen oxides can be reduced by spraying ammonia or urea into the hot exhaust (a technology called selective non-catalytic reduction). Acid gases can be removed by a "dry scrubber," which sprays wetted lime powder into the hot exhaust. Dry scrubber systems can also trap up to half the mercury, with the rest controlled by blowing activated charcoal into the exhaust gas to adsorb some of the mercury.

The products of these catalytic and chemical reactions are in the smoke emitted by the power plant as small particles and must be removed. These particles are called "fly ash" because they are light and tend to fly around in the hot flue gas and are composed of lime salts, activated charcoal containing mercury, ordinary smoke and soot (which are themselves carcinogenic), dioxins, and metals (like lead, cadmium, and nickel) . Fly ash is usually removed by a "bag house," which works like a giant vacuum cleaner with hundreds of fabric filter bags. Some plants use a different device, called an electrostatic precipitator, which uses electrically charged plates to capture the small particles of fly ash, much like a television screen attracts house dust.

And this is where James' problem arose. The toxic gunk that was removed had to be stored. In order to attract power plants to Oklahoma, the state had set aside a valley near Mangum in southwestern Oklahoma as an impoundment. The plan was to fill the impoundment with the solid waste produced from the power plants. However, this region of the state was a gypsum karst, which seemed to an untrained observer to make a perfect site for such waste storage. Karst is a type of landscape found on rocks that can be relatively easily attacked by water. The appearance of the landscape shows closed surface depressions and a paucity of surface streams—which all sounds well and good. However, karst has a well-developed underground drainage system. While karst is only 10% of the land area in the world, as much as a quarter of the world's population is supplied by karst water. The karst system can have poor ground water quality because of lack of filtering action and difficulty in designing effective monitoring systems around waste facilities.

Dumping toxic sludge from the power treatment plants onto the ground might contaminate huge amounts of ground water and destroy good agricultural land. Numerous scientific watchdog organizations had raised such concerns.[3] However the cost of containment, including concrete ponds, waterproof ground coverings, and monitoring, would be excessive. And large expenditures of money were not popular politically. As an engineering professional, James felt he had to fight this, but it was an uphill battle. George was in a worse situation. His boss, a political appointee, was the one who had given his office's okay to the impoundment site near Mangum initially. Now that the press had found out about this, it was about to become a loud public battle with emotions running high on both sides. And the noise from fanatics on both sides would make it even more difficult to come to a reasonable solution through negotiation. If there were only some way to have a truly neutral third party show that the site was not suitable, the problem would have to be addressed. But it was about to become too late for that....

The whole situation gnawed at George's stomach as he walked to Agriculture Hall to give a lecture on the effects of eutrophication. Eutrophication is a process that results from accumulation of nutrients in lakes or other water bodies. Algae growth is limited by the available supply of phosphorus or nitrogen. If these nutrients are added to the water, algae and aquatic plants can grow in large quantities. When the algae die they are decomposed by bacteria, which use dissolved oxygen. Dissolved oxygen concentrations can drop too low for fish to breathe, leading to fish kills, and the rapid decomposition of algae scums created a foul odor. Eutrophication would be one more environmental problem they would have to deal with if these power plants were built since not only waste but an increase in water temperatures can reduce the amount of oxygen.

James arrived at the Ag building and nodded to Herb Sanderson, who introduced him to his ground water class. The students seemed oddly excited to hear about a subject as obtuse sounding as eutrophication, asking questions specifically about how leaking septic systems contributed to nitrogen and phosphorus in runoff. James had more experience than he ever wanted in working with leaking septic systems—the worst and dullest part of his job. Domestic sewage is an important source of phosphorus contamination of surface water. Phosphorus is essential in metabolism so it's always present in animal waste. Orthophosphates and polyphosphates can additionally be contributed by detergents.

After class James asked Herb why the students seemed so excited. It turned out that Herb had recently returned from a conference and had some new ideas for laboratory exercises in his class. There was a program in Michigan in which students set up field experiments to monitor whether sewage had leaked from septic systems. Herb had assigned his students such a project and they were about to head out to the field to do some waste monitoring.

"So, you are using students to detect water contamination?" asked James. "What do you do, have them drink the water and then monitor them for the runs?"

"Ha, ha. Seriously, they simply flush a relatively harmless dye down the toilet and set up monitoring stations. Plus do a host of other measurements. It's a real learning experience."

James was getting excited. "You could also use this to detect leakage from hog lagoons or other waste containment sites?"

Herb replied, "Sure, but I haven't heard of that as a student project. I have the conference schedule here if you want to look up more information on this." He made James a copy of the page out of his conference program.

Detecting Leaking Septic Systems in the Rouge River Basin

> This work is a 2-year study of pollution associated with leaking septic systems in the headwaters of the Rouge River, in the Detroit metropolitan area. The survey began in 1994 as part of a public health partnership between several organizations and the Rouge River National Wet Weather Demonstration Project, which provided funding. College students were selected to begin the project, first taking measurements of dissolved oxygen, pH, turbidity, and temperature. They also collected samples for bacterial and macroinvertebrate analyses in each of the eight tributaries. Then, based on the results of the analyses, certain areas of the river were targeted for dye studies, using an innovative technique. Packets of activated charcoal were secured in the river near homes to be tested, and fluorescein dye was introduced into the septic systems. The packets were retrieved after a week and immersed in a potassium hydroxide solution. If the charcoal had absorbed any of the dye, it would be released into the solution, creating a positive test. Data collected over a 2-year period showed that 45 percent of the homes tested positive for leakage of septic wastes into the river. As a result of this study, public awareness of septic tank maintenance and its impact on river ecosystems was enhanced. For more information, contact the Michigan Department of Environmental Quality (see EPA's *The Water Monitor* 1996).

"Thanks Herb, you are a genius! Can you meet me for lunch at Joe's in two days to meet a colleague of mine? I have a proposition I would like to discuss with you!"

James rushed back to his office, and immediately made several phone calls. He outlined his plan to George and invited him to lunch. He also invited a colleague, Jeanne Blaney, from the OSU Center for Sensors and Sensor Technologies [4] who was up to date on a lot of ways to detect particular kinds of chemicals.

As planned, Herb, George, Jeanne, and James met for lunch at Eskimo Joe's on Tuesday. With Jeanne was a young woman named Emmie Carmichael who was a first year graduate student looking for a research project. James outlined the events that had taken place in the last few days, providing background information on power plants and the effect dumping power plant sludge on unprepared ground would have on the water system.

"Well, James, that is interesting and, while I appreciate the free lunch, I am not sure why you want me to become involved," Herb said. "Sounds to me like George needs to go to his boss and get the site changed with your backing."

With a sigh James outlined his ideas while the rest of the group ordered lunch. A state agency delivering a negative finding at this point would almost certainly cost George his job, and most likely would be ignored since they had been against the site all along. James, having sided with George in previous disputes, would also be automatically seen as having taken sides in the debate. "It's ridiculous," James concluded. "We're past the point where reason and science will be listened to. And the media in the person of Misty Dorfmann will sensationalize any lack of consensus. This kind of coverage really polarizes what is already a complex issue."

"I still don't understand our role in this," said Herb, echoed by Jeanne. "It just sounds like more reasons for us to stay as far away from this as possible."

"Remember what you told me about your students looking for sewage contamination of water, Herb?" reminded James. "Isn't this exactly the same thing? If a team of students did some studies that showed that leaching of heavy metals into the ground water was a problem it would be awfully hard to pin a political motive on them. And the media would love it, with all the resulting good publicity for OSU."

Jeanne spoke up, "Okay, that explains why Herb is here. What about Emmie and I? This is a political hot potato and I am not sure what our role is. You know we're not a commercial laboratory that can run samples for you...."

James explained that by releasing fluorescein dye into the water impoundment, the presence of the dye in ground water or nearby streams would indicate that any water-soluble toxins could potentially escape the impoundment area. The idea came from the class project that Herb's students were doing. The problem was that field studies used a fluorometer to detect the presence of the dye and the instruments were expensive, costing about $12,000 in a typical configuration [5]. Jeanne's role would be to suggest much less expensive sensing technologies, which could be built for field measurements by the students.

"Hmm.... This might be doable. All you want to do is detect the presence of fluorescein, right?" asked Herb.

James explained that it would also be nice to measure the pH of the water as well as the oxygen content. The pH affected the amount of fluorescence, which would be needed to calibrate the measurements. The dissolved oxygen (DO) would help determine the effects on any marine life as well as the general change in health of the environment. James had done a little reading, and it seemed that both pH and DO could be measured optically, perhaps using the same instrument that was developed for measuring dye concentration.

Emmie spoke up for the first time. "Dr. Blaney, we are learning about this in your class! I think this would be a great project for me." She went on to regurgitate the basic lectures on fluorescence. Dye molecules have electronic structures similar to that of atoms. Every student learned in physics that each atom has a specific configuration of negatively charged electrons that surround the positively charged nucleus of protons and neutrons. Quantum mechanics determined the precise energy of any electron given the particular state it was in, whether it was an atom or a molecule [6,7,8].

"Wait a minute," James interrupted. "I am a little rusty on this stuff. What do you mean by state?"

A state was the name given to the particular orbit an electron was in. Each state had a given potential energy—if an electron was to change from a lower energy state to a higher energy state, some input of energy was required. Similarly if an electron moved from a higher energy state to a lower energy one, the electron had to lose some energy. This was the key point. Some device was needed to give energy to the dye molecules, taking them from a lower energy state to a higher energy state. When the molecules eventually returned to the lower energy state, they lost energy in the form of light, which was easy to detect.

"So, how do you give energy to these molecules?" asked James. "Aren't they too small to see, let alone give energy to?"

That turned out to be relatively simple. The easiest technique was to irradiate the molecules with light of a particular wavelength, which would be absorbed, causing the electrons to reach the excited state. The excited state would then decay, emitting light of a different color. By measuring the amount of light at specific frequencies, one could, at least in theory, determine the amount of a substance present. This general principle was how black light posters worked. Another way, which worked better for atoms rather than molecules, was kinetic excitation. If one atom going very fast slammed into another atom, there was a chance the energy would knock one of the atoms into a higher energy level, or excited state. However, for molecules this tended to break them apart.

Jeanne interrupted, "Emmie, this is a good project for you, and I may be able to fund it out of a startup grant program I have if you can submit a good proposal on it. However there are a lot of things you still need to learn. First, you need to figure out how to collect and analyze the spectra, and do it at a reasonable cost. There are also complicating factors in the analysis. For example, you need to somehow make sure the light of your excitation source does not overwhelm the weak light from the fluorescence. Also contaminants can emit light of nearly the same color, making it difficult to distinguish between them and the dye. And you need to investigate how to measure DO and pH."

"pH should be easy," responded Emmie. "That is just a color change in a solution. I did that in basic chemistry. Also, can't you buy inexpensive pH meters?"

"The color change might be able to be done optically, but you have to do it in the field without any laboratory glassware at hand...."

James interrupted, "George, do you think this will work?"

"Well, it solves our problems. We need to get on it right away though. If this isn't going to work we need to know in no more than a month. Sounds like what we need to do is get this instrument built, then reassess if student teams can really carry out this research. We are going to need a lot of these sensor packages to cover a large area. We have no idea right now where the leached toxins will flow to. Herb, would you be willing to have your students work on this?"

Herb hastily swallowed a big piece of the "Foul Thing®" he was eating. "The only question I have is one that James brought up earlier. We are not going to be able to afford a good fluorometer. I'd love for my students to learn more about the inner workings so they don't treat it like a black box. But they are not technical wizards. It would have to be pretty easy to use. And I have real doubts whether you can make one as sensitive as a commercial instrument for a reasonable cost."

As the meeting wrapped up, Emmie and Herb agreed to come up with a rough idea of what would be required to measure dye concentration, pH, and DO. Emmie would work with some of Herb's students to calibrate the instrument they designed with known samples, and then they would all meet to reassess the project.

Emmie and Herb talked about the project as they walked back to campus. Emmie's enthusiasm was boundless, but Herb tried to put a damper on it. "You know, Emmie, there is more to this than just building the device. You are going to have to calibrate it somehow, and find the upper and lower limits of its detection range. Plus there is going to be entering the data from the water you measure into a matrix to plot it...."

In the middle of the next week, James received the following e-mail:

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Date: Thu, 23 Aug 2001 14:32:54 -0500
(CDT)
From: emmiecar@sensors.okstate.edu
Subject: water samples
To: Herb S<herbivore@okstate.edu>,
James S<madisja@okstate.edu>
X-Mailer: Sun(TM) Web Access 1.2

Dr. Sanderson and Dr. Madison-

I want to tell you I am really excited
about this project!  I've found some
commercial sensors which will measure pH
and dissolved oxygen optically.  They are
both made by the same company:  Ocean
Optics.  You can get to their web page at
www.oceanoptics.com.  I have also found a
paper about the effect of pH on
fluorescein.  It is in the Journal of
Luminescence, vol. 10, page 381, 1975.  I
have also found out a good place to learn
about the toxicity of this dye.  You can
get MSDS's for this stuff at several
sites.  One is
http://research.nwfsc.noaa.gov/msds.html.
I am well on my way to designing the
instrument, and using the Harris book as
my bible :->

Have a Great Day!

Emmie
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Questions

1. Summarize this case. What technological solutions are proposed?
2. There are several significant aspects to this project that Emmie's team has not yet addressed, what are they?
3. Are there any moral, ethical, or legal issues associated with this case?
4. What are some design issues for building an appropriate detector? How would you take care of some of the complications listed in the case?
5. What would the positive and negative effects be if the student teams succeeded in proving that leaching of toxins into the ground water did in fact occur as hypothesized by James and George?

References

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3. Union of Concerned Scientists. Environmental impacts of coal power: wastes generated. http://www.ucsusa.org/energy/c02d.html
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Date Posted: 10/15/02 nas

Case Follow-up: Emmie's Assignment

Emmie had been up late for several nights, going to the library to learn about how to measure fluorescence. The more she read, the more confusing the subject became and the more she realized that she should have paid closer attention in her freshman chemistry class. There was a huge amount of literature on fluorescence, spanning every scientific or engineering discipline she had heard about and some that she had learned existed only since beginning her literature search.

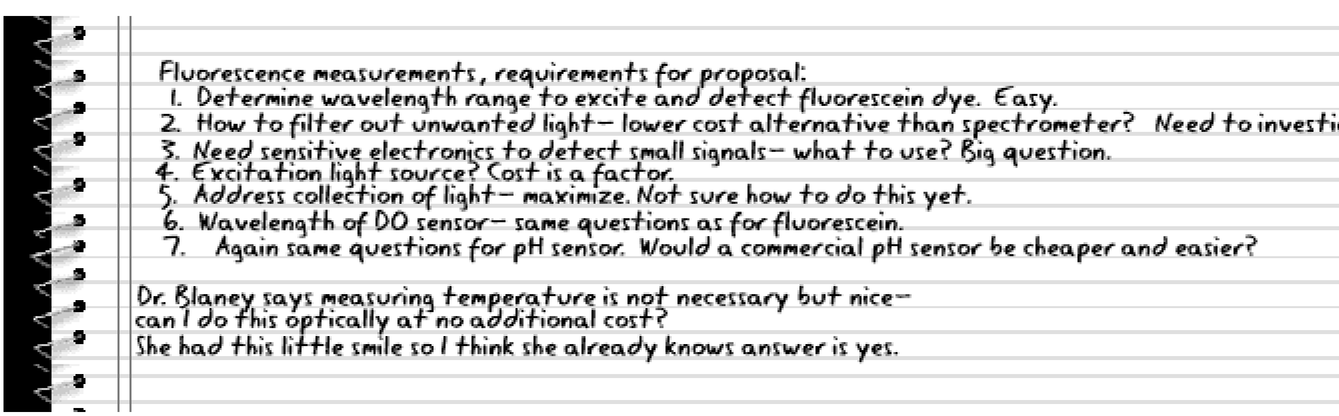
Dragging herself out of bed that morning, she had stopped by New York Bagel to get an extra large mocha to give her the sugar and caffeine jolt she needed to keep awake during her weekly meeting with her advisor, Jeanne Blaney, who was a notoriously early riser. As she had feared, Jeanne asked her how the project was going and what progress she had made.

"Gosh, Dr. Blaney," Emmie said. "I feel like I am moving backwards. The more I read, the less I seem to understand. It seemed pretty simple at first, but every paper I read has some new thing I need to consider. It seems nearly impossible for me to consider all these factors to make sure that any measurement I take will be correct. I mean, things depend on pH *and* concentration *and* temperature. To understand concentration dependence, it looks like I need to calculate some sort of dipole energy transfer, which seems really hard. And I haven't even started on DO or pH measurements yet."

Emmie's distress reminded Jeanne of her own experiences in graduate school. She had to quickly change her laugh to a cough after seeing the expression on Emmie's face. "Look Emmie, you are getting sidetracked with details. As you first thought, what we are trying to do here is pretty simple but there are a lot of complicating factors if you want to be extremely accurate. Let's forget about all of those and make the simplest possible system—then worry about complications if the system doesn't work right."

As the meeting wore on, Emmie outlined a series of all-optical measurements that could measure DO, pH, and dye concentration. Each measurement utilized a separate sensing element that could be measured optically. She could see that Dr. Blaney was convinced that the measurements were possible. The only reservation she expressed was the cost of the system Emmie outlined, which used a commercial spectrometer to measure the spectra from the sensing elements.

By the close of the meeting Emmie found herself agreeing to put together a proposal to address several of the key issues which had to be resolved before the engineering work on a compact, low cost system could begin. Emmie walked out of the meeting with a list of items she needed to address before Dr. Blaney would buy her the equipment she needed. Glancing at the list she realized her late nights of reading had paid off; she already knew the answers to many of the items on the list....


Fluorescence measurements, requirements for proposal:
1. Determine wavelength range to excite and detect fluorescein dye. Easy.
2. How to filter out unwanted light— lower cost alternative than spectrometer? Need to investig
3. Need sensitive electronics to detect small signals— what to use? Big question.
4. Excitation light source? Cost is a factor.
5. Address collection of light— maximize. Not sure how to do this yet.
6. Wavelength of DO sensor— same questions as for fluorescein.
7. Again same questions for pH sensor. Would a commercial pH sensor be cheaper and easier?

Dr. Blaney says measuring temperature is not necessary but nice—
can I do this optically at no additional cost?
She had this little smile so I think she already knows answer is yes.