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ADVANCED DETECTION TECHNOLOGY FOR EARLY WARNING – THE KEY TO OIL SPILL PREVENTION

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ABSTRACT: This paper discusses the development of an oil spill detection and alarm system that provides industry with a reliable, cost-saving mechanism for containing and/or preventing accidental discharges of hydrocarbon-based pollutants.

By utilizing an automated spill detection system, hydrocarbon releases are detected in real-time (analogous to a 'smoke alarm' for oil spills). Early warning and automated response capabilities allows early containment of oil pollution, thereby reducing the volume spilled and minimizing damage to the environment, wildlife, public waterways and/or commercial assets. This technology provides a new weapon in the pollution prevention arsenal, offering Health Safety & Environment (HSE) personnel a critical compliance tool in accordance with National Pollution Discharge Elimination System (NPDES), US EPA Spill Prevention Control & Countermeasure (SPCC), and other regulations stipulating spill prevention, planning and response.

This paper details: 1) Development of a reliable, economical, optical, non contact, UV/fluorometry-type, hydrocarbon pollution detection sensor system 2) Performance results drawn from an array of performance tests and real-world deployments, 3) A variety of existing applications and deployment opportunities for which this new technology offers a reliable solution and easy-to-use tool for both regulatory compliance and realization of cost benefits associated with minimizing spill risk(s).

Design features have evolved to reflect feedback from existing industrial users, as well as input from environmental consultants and regulatory agencies. These key system attributes include: 1) Near-zero maintenance, 2) Micron- level sensitivity for a comprehensive range of oils (from crude-oil to jet-A), and 3) Sensor/system flexibility and adaptability for varied application requirements and a wide range of installation settings (i.e. freshwater, marine, industrial, harbor, offshore, etc.).

Finally this paper describes how any entity that produces, stores, uses, or transports hydrocarbons, can best employ the detection sensor/alarm to realize cost-benefits, strengthen compliance, and eliminate the expense, environmental damage, and bad publicity inherent with any oil spill.

I. INTRODUCTION

Oil spills are a global concern and worldwide dependence on fossil fuels and oil derivative products are at historic highs for production, transportation, storage, and consumption. While major offshore spills occasion attention-grabbing headlines, tanker spills and comparable large-magnitude spill events constitute just a fraction of oil pollution to the environment. In point of fact land and inland waterway based spills result in much greater aggregate damage to the environment and cost to society than do marine spills [1], but draw considerably less public attention. According to the US National Academy of Sciences publication, Oil in the Sea; "Nearly 85 percent of the 29 million gallons of petroleum that enter North American ocean waters each year as a result of human activities comes from land-based runoff…[while] less than 8 percent comes from tanker or pipeline spills".

It's evident that both offshore and onshore spills are of growing public concern. However it seems that a disproportionate amount of emphasis is placed on prevention and response to spills at sea (which, through concerted efforts in recent decades, have been statistically fewer with sharply downward trending frequency). Meanwhile attention to and prevention of shore-based oil pollution sources lags well behind offshore efforts, whilst the innovation and implementation of new processes, methodologies and technologies necessary to protect ourselves and the environment from sources of land-based oil pollution sources are being severely outpaced by the growth, demand, and omnipresence of oil.

With these premises in mind, the following describes recent successes in development and use of new sensor technology for the prevention, detection, and early warning/containment of oil spills. The primary focus of this paper is on new sensor technology, intended to help prevent and minimize the impact of inshore and freshwater oil spills, with particular emphasis on industrial applications. The uses of UV/fluorometry-type sensors for inland and coastal waterway applications are also discussed, as well as adaptation of for use in the offshore environment.

Prevention and early containment of spills benefits everyone: the public at large, stakeholders of watersheds and waterways, business interests (after all spills are expensive), the ecology of natural habitats, and the environment as a whole. Spill prevention and reduction through remote early detection provides a proverbial "win-win" solution and, when implemented, greatly reduces the risk of significant spills as well as cumulative harm to the environment. Use of UV/fluorometry-type sensors for this purpose is now validated by early adopters of this new technology who are demonstrating that real-time spill detection offers a powerful tool for preventing and containing spills that otherwise go undetected until it is too late.

A few factual tidbits to provide perspective:

- **The US consumes ~21 million barrels per day (~25% of world's total)**
  (*US Dept of Energy*)

- **12,000 – 15,000 oil spills are *Reported* annually in the US** [unreported totals obviously higher]
  (*Texas Water Resources Institute*)

- **More than half of reported spills in the US are inland incidents**
  (*various sources*)

- **25 Gallons of oil can spread a visible sheen over an area of one square mile**
  (*Metcalf & Eddy*)[6]

II. GOALS

In developing an oil spill detection sensor, the goal has been to create an early detection mechanism for spills or discharges, accidental or deliberate, for both freshwater and marine environments. Since its inception, the scope of the sensor's design has evolved to address an ever-widening range of applications and system features. However, the fundamental sensor attributes listed as goals at the outset remain at the core of the design: 1) reliable detection of oil sheens and slicks on water surfaces, 2) non-contact sensor design, facilitating highly-sensitive oil detection without the instrument contacting the target water/effluent, 3) impervious to environmental conditions, 4) remote and autonomous operation, 5) operable in excess of 5-meter range above monitored surface (i.e. tidal range), 6) adaptable and scalable, 7) easy to install and operate, and 8) a commercially viable, economical, low maintenance sensor package.

III. PRINCIPLE OF DETECTION

Oils are known to fluoresce, and the newly developed oil detection sensor discussed herein detects the presence of oil by means of exciting and measuring fluorescence. Fluorescence is an optical phenomenon in which a compound absorbs light at one wavelength and emits it at a longer wavelength [2]. When fluorescent compounds are excited, some of the energy is absorbed through the excitation of electrons to higher energy states. Once the light source is removed the excited electrons fall back to their ground state, giving off light in the process. This process is very similar to what makes glow-in-the-dark materials possible, except it takes place in a much shorter time period. Because some rotational-vibrational energy (i.e. heat) is lost in the absorption-emission process, the wavelength of the emitted light is always longer than the wavelength of the absorbed light. Typically the absorbed light is in the ultraviolet (UV) range and the emitted light is in the visible range (the visible longer-wavelength light often appears violet or blue). For example, oils typically absorb light between 300 and 400nm, and emit light in the 450 to 650nm range.

Fluorescence detection, or fluorometry, is by no means new technology in and of itself. Typically, fluorometers use spectroscopy methods for fluorescence detection in the form of flow-through or in-water systems. Often these comprise sophisticated lab-quality instruments, used either for scientific research or as in-line water analyzers. These fuorometers offer high sensitivity and multi-channel capabilities, but as such also tend to be prohibitively expensive and impractical for use as remotely deployed field units or in networked arrays. The flow-through technique is also susceptible to bio fouling and oil staining on the sampling tube/mechanism and thus requires significant maintenance. And in-water sensors are of course subject to bio-fouling and troublesome installation and maintenance issues. By contrast, the design of this new spill detection sensor, while based on the same fluorometric principles, is a downward looking, non-contact, optical sensor, which is installed high above the target surface thus freeing it of maintenance, fouling effects and deployment limitations, and making it favorable for field installations.

Within this above-surface UV/fluorometry-type optical sensor, a high-power Xenon lamp is used to produce a high-energy light beam. This source light is then filtered and sharply focused into a conical beam so only desired wavelengths of light are projected onto the target area. Any oil present in the target area will fluoresce and subsequently emit light of its characteristic wavelengths. This light is then processed by the sensor's proprietary scanning optics and digital signal processing system, which detects the fluorescence characteristic of oil.

The sensor's detection of oil is predicated upon differential measurement, meaning it is based on anomalous signal return within a target area when oil is present. Normal ambient conditions constitute the baseline reading, or 'zero point', and a sensor state of "no oil detected". If oil is present, the signal return is greater than normal ambient conditions, triggering detection and an "oil detected" alarm state. If oil is present in varying amounts, the signal return is proportional to the level of fluorescence (indicative of oil or PAH/aromatic constituents) measured within the sampling area.

IV. DEVELOPMENT

Using the basic physical principles of fluorometry, and aforementioned list of sensor attributes and design objectives, the developmental stages were begun by studying the physical characteristics of oil and conducting laboratory experimentation with various light sources, optics, and detectors. Principal efforts focused on those oils and petroleum-based fluids, commonly referred to as PAH (Poly Aromatic Hydrocarbons) and BTEX compounds (Benzene, Toluene, Ethylene, Xylene). The PAH and BTEX fluids chosen for study were selected because they are the most prevalent, and/or deemed particularly toxic, and/or perceived to be of greatest concern by the industry management, end users, and government entities (regulators) consulted in this regard. For example initial fluids studied included: crude oils, heavy fuel oils (e.g. bunker fuels, fuel oils #2, #4, #6, etc.), lube oils, motor oils, hydraulic oils, turbine oils, diesel, jet fuel, naphtha, kerosene, mineral oil, various process oils, etc. Numerous edible oils such as soybean, corn, olive and palm have also been examined, as well as water-soluble glycols and other compounds of interest.

It is important to note that different brands or types of oil within the major 'classifications' (e.g. "diesel fuel-oil") originate from many different sources, contain various additives, and consist of differing concentrations and compositions. From product to product within a given class of oils there is inherent variability in fluorometric characteristics and how the oil/pollutants will respond or 'appear' to the detector when excited with UV light. Rather than attempting to analyze small differences and degrees of variability between every type of oil in every possible concentration and state, priority was given to developing and testing a field sensor that could qualify the presence of the widest possible range of oils with high reliability and detection probability; a 'broad range' hydrocarbon detector.

Test results are of course limited to the specific oils tested within the given set of conditions present during testing. However, consistent with development of a broad-range detector, results gained from testing specific products against the detector have often proven reliable to successfully predict or infer similar characteristics and 'detectability' of similar oils, regardless of slight variability from product to product. Moreover, for users interested in detectability of particular oil(s) of concern, for example an exotic oil or process oil, it has become a common exercise to test samples of oil using detectors in the lab, or on site in the field, to verify high probability of detection and to characterize and document detector proficiency for specific oil-based product(s) heretofore untested.

Figure 2 illustrates one of the initial attempts to characterize oils when exposed to a broadband UV light source. The results are from tests performed during the development of the instrument. The tests were conducted using a laboratory light source and receptor, and while these test have been repeated employing a variety of different equipment, setup parameters, and intent, the results shown in Figure 2 illustrate a representative estimate or 'spectral benchmark' for subject oils' fluorescence when irradiated with a UV light source. For reference, Fingas and Brown address a more thorough treatment of this topic in their paper entitled "Review of Oil Spill Remote Sensing" [3].

As the result of laboratory experimentation during initial development, a high-powered Xenon strobe was selected for the sensor's integral light source, and was coupled with a suitable power supply.

This same flash and power supply has proven to be highly effective throughout the sensor's evolution. One key criterion for developing the flash assembly was enough output intensity to enable detection of small surface sheens from a distance of 5 meters above the target surface area. Presently this 5-meter limit is the approximate upper boundary for reliable detection for most oils of concern; however ongoing tests confirm that with further improvements to optical components the sensor's detection range may be increased.

Other critical components required for the output/optical subassembly are the parabolic reflector, which focuses/collimates the conical beam onto target area below, and band pass filters, which limit the energy output to the desired spectral range. Each of these components have been integrated, tested, and optimized based on extensive performance testing and best available parts and materials.

Similar to the development of the sensor's optical subsystem, a proprietary set of photo detectors have been integrated to provide the necessary receptor attributes that allow for accurate measurement of the presence of oil, based upon performance ongoing testing and field trials.

Today these subassemblies, along with requisite electronics and microprocessor, are compactly integrated within a stainless steel weatherproof enclosure (roughly 10x12x14 inches). The housing is also fitted with valve fittings and a vent, so that an air-purge system may be added to satisfy installation requirements in explosive gas locations, as are common in refineries and oil terminals. Alternatively the sensor may be built within an "explosion-proof" housing for use in hazardous/explosive environments.

The initial system was designed for use with alternating current (AC) power, then later modified for operation with an integrated direct current (DC) power source (i.e. batteries and solar panels) to facilitate deployments in remote settings. For installation convenience and other practical reasons (such as size and mitigation of electro-magnetic interference), the DC power system is housed in a separate weatherproof enclosure that may be collocated with the sensor, or installed away from the sensor to gain optimal exposure to sunlight for solar recharge. Similarly, when wireless communication is used (e.g. spread spectrum radio, satellite, cellular, etc), the communications package is housed together with the DC power supply and may be installed for optimal orientation.

Initial prototypes communicated using a basic RS232 protocol and a terminal program such as Windows Hyper Terminal. Typical field applications have since dictated the addition of RS485 capability, as well as analog outputs such as 4-20mA analog current loop and/or dry contact relays (alarm switch relays) for direct connection to industrial process control systems.

The detectors' alarm relays and/or analog output are often wired directly to Programmable Logic Controllers (PLCs) for automated actuation of a valve, shutting off a pump, and/or activating local audio/visual alarms the moment a spill is detected. For example; the detector senses a spill and automatically actuates a valve, causing any oil present (or yet to come from upstream) in the effluent discharge to be diverted to an area of secondary containment, where it can be cleaned up after the event with no harm to the outside environment. This method for automatically containing a spill the moment the event is detected – with no human intervention required – enables the detector to be used for automated spill *prevention*, as opposed to only spill *minimization* via early warning and response. Refer to Figure 8 (sensor coupled with PLC for automated spill diversion to secondary containment) and Figure 6 (sensor coupled with PLC for automated containment of spills within a sump).

Wireless communication is required for many remote-monitoring applications today. The automated detector has been designed accordingly to output compatible data signal, digital or analog, for use with any type of wireless telemetry (radio, cellular, or satellite) for real-time spill monitoring.

During the development period proof-of-concept and prototype testing was successfully completed, extensive lab and field-testing conducted (see Figures 4 and 5), and first and second-generation production units built that incorporated upgrades based on experience gained from real world installations and initial users' input. Critical (and much appreciated) feedback was gained from consultation with early customers such as Shell Oil (refinery applications) and Dominion Transmission (remote compressor station applications). They deserve credit for being on the leading edge in their respective industries, successfully implementing this new spill prevention and alert technology. Today this UV/fluorometry-type sensor complies with the US EPA's standard test procedure for evaluating leak detection methods, and is in the process of being commercially patented.

V. SENSOR PERFORMANCE: RESULTS & LESSONS LEARNED

Many problem-solving opportunities arose during the development process. One of the obvious challenges with an optical sensor is that it must have a clear 'view' of the area to be sampled. If the optical path is blocked, the detector is effectively rendered 'blind'. Through testing and field experience it has been determined that the light beam is unaffected by light haze, smog or fog, but as a rule of thumb if the path interference is too thick for the human eye to see through, it will also affect optical sensor performance. For example a series of tests was conducted using a large chunk of dry ice and tub of water containing an oily sheen. In this test a visually impenetrable fog was generated, which effectively prevented the sensor from being able to detect the oil sheen below. However visually impenetrable fog is the far extreme, and in point of fact this scenario has not occurred or presented any problem in any existing field installations.

Likewise partial path interference (physical blockage) does not necessarily disable the sensor's ability to monitor and detect oil. For example, in the photograph shown in Figure 6, the sensor is installed such that it is peering through a metal grate into a containment sump below. Although signal return is attenuated about thirty percent in this example (vis a' vis the grates partial blockage / impassability), the signal to noise ratio remains the same as with no grate. That is to say the 30% overall signal loss has no adverse affect on the detector's ability to reliably differentiate between clean water and oil-polluted water beneath the grate. A number of users have taken advantage of this capability; while others have simply cut a small window for the sensor to 'peer' through in grated-sump applications (refer to Figure 8).

While the sensor needs to be mounted roughly perpendicular to the surface below, it has been determined that there is a tilt tolerance of about 15˚, which helps a great deal with certain applications such as buoy-based installations where a fixed perpendicular orientation is not viable (see Figure 12).

Naturally one of the biggest fears for sensor operators is false detection, and there are other substances that do fluoresce in a manner similar to petroleum-based fluids. For example, white paper and white fabrics can trigger a false positive (much as a white t-shirt glows under black light). Fortunately items that may cause false detection are few, and are not prevalent in typical installation environments. In the case of some non-oil substances known to fluoresce (for example fluids containing fluorescing rust inhibitors), varying the optics and/or detector configuration has been successful in eliminating sources of false positives, in essence 'filtering' them out. More common wildlife and debris such as birds, algae, seaweed, sea foam, driftwood, and plastic bags have not been problematic sources of false detection. In fact to date there have been no problems reported by users with sensors in the field with respect to naturally (or unnaturally) occurring environmental phenomena causing false detections. Nor have ambient conditions such as sunlight, waves, or water currents been shown to have any adverse affect on the ability for the UV/fluorometry-type sensor to detect hydrocarbons.

During sensor initialization and setup a “baseline” measurement is made. This baseline measurement is internally recorded, and is used to establish normal operating conditions (either with clean water or with a normal level of oily sheen or other chemicals/materials typically present). In addition to monitoring for oil-on-water, the monitored-surface may also be normally dry (or periodically wet/dry) ground or pavement – that is to say water need not be present. This one-time baseline measurement establishes the zero point (in effect zeroing-out naturally occurring signal level or ‘noise’) in order to account for ambient conditions. This provides a normalized-background that contrasts with and differentiates anomalous events indicative of oil. Varying water level, such as tides, or rising/falling storm water, causes the ambient baseline to shift up or down as the water periodically rises and subsides. In order to account for and cancel out this background shift, the sensor uses an algorithm (or more simply stated a ‘rolling average’) called “adaptive baseline” mode. For example, in a cyclical tidal setting, or in applications where storm water surges occur, the sensor may be programmed to operate in adaptive baseline mode in order to normalize the effect.

Another interesting attribute discovered with respect to this UV/fluorometry-type sensor is its ability in many cases to detect oil dispersed in water, as well as fluorescing compounds such as glycols that form solutions when mixed with water. As an example, a prospective user expressed interest (promulgated by a costly pollution incident) in evaluating the sensor’s ability to detect small concentrations of wire drawing fluids used in their industrial manufacturing process. They were hopeful of detecting these potential pollutants at a concentration of 0.1% because this was the concentration measured during clean up of their accidental discharge. The manufacturer (end user) provided samples of these various lubricants, each of which mixed or dispersed near-instantaneously when introduced to water. In testing, the sensor detected each of the different fluid samples at a concentration of less than 0.1%, and was able to reliably detect one of the lubricants dispersed in water at a concentration of only 0.001%.

At the prototype stage the sensor was programmed to sample every 30 seconds, based upon preliminary user requirements in harbor settings. This initial configuration proved to be impractical for installations where water moves rapidly enough to transport broken spills past the sensor prior to detection (i.e. streams and sewers). To overcome this, tests were conducted using a flume (approx. 7 ft./minute flow rate). Based on experimental test results, the sensor is now user-programmable for variable sampling rates. For “continuous” sampling a 2 Hz sampling mode may be used. In this sampling mode the strobe (excitation source) is fired twice each second and the monitor outputs a signal value for each sample. Alternatively there is a 5-second sampling mode, in which the strobe takes a burst sample (typically 10 samples at 100msec intervals) once every 5 seconds, and the value output is an average of this periodic burst sample. This enables near real-time monitoring, whereby the detector can be programmed to sample near-continuous, or less frequently, as appropriate for specific application requirements and/or power budget.

VI. APPLICATIONS

Initial development of this oil spill detection system was promulgated by perceived utility in the coastal/marine environment, and in ports & harbor settings. For example single units or sensor networks would be strategically placed to monitor fuel piers and bunkering facilities, marine terminals, shipyards, naval installations, marinas, storm water culverts/outfalls, etc., throughout a port. Ultimately this sensor technology has been proven well suited and valuable for these types of applications (reference Figure 10 & 11).

The range of applications that has turned out to be most significant reside in the realm of freshwater and inland waterways, particularly at or near petrochemical plants and industrial facilities. End users in this sector include: refineries, terminals, tank farms, power plants, paper and steel mills, heavy industry/manufacturing, water treatment plants, food oil plants, and more. Figures 6, 7, 8 and 9 exemplify typical installations in these sectors. In point of fact any facility that stores, processes and/or utilizes large quantities of oil is (or should be) concerned with real time detection of errant spills. As such these entities and corresponding personnel may now choose to implement early warning oil sensing systems in keeping with “Best Available Technologies” (BATs), “Best Management Practices” (BMPs) and Best Engineering Practices (BEPs) for real-time notification and early containment of spills.

There is a growing awareness and mandate at such plants and facilities to protect against spills going undetected prior to discharge into the environment. In the US this need is driven in part by requirements for ‘oil-centric’ facilities to update their SPCC plans, as mandated by the US Code of Federal Regulations (CFRs) as overseen by the US EPA. For example remote spill detection sensors may be used to support conformity with regulations listed in sections of CFR 40 parts 112.7(a), 112.8(b), and 112.8(c) [4]. These regulations apply to facilities that produce, process, store, use, and/or transport large quantities of oil (greater than 1,320 gallons aggregate or any single tank larger than 660 gallons). The US EPA has estimated that there are over 400,000 regulated facilities in the US, 220,000 of which consist of: oil production facilities, refineries, pipeline/storage facilities, bulk stations and terminals, fuel oil dealers, electric utility plants, chemical plants, and manufacturers. At present the updated CFR 40 rules mandate that facilities “must prepare or amend AND implement SPCC plan by July 1st 2009”.

From a regulatory perspective, oil detectors may also be used to augment a facility’s strategic approach to meeting their NPDES permit requirements and like regulatory requirements both in the US and abroad. Considerable additional motivation for potential point-source polluters also exists, attributed to the fact that spills are expensive to cleanup and mitigate and are the source of costly regulatory fines as well as bad publicity. Indeed there is ample justification for utilizing early warning detection and alarm capabilities from a cost-benefit perspective, in order to prevent or contain spills before they becomes disasters and meet with public outcry

In addition to spill monitoring deployments along coasts and in ports & harbors, or installing spill alarms as safeguards along industrial spillways, a third major application is envisioned for remote spill detection sensors: protection of sensitive wildlife habitats and/or aquaculture/fish farms. In this scenario detector(s) are installed beyond or at the perimeter of a sensitive habitat such as an estuary, wetlands, bird sanctuary, or shellfish bed. If a spill encroaches upon the boundary of a protected area, on an incoming tide for example, the remote spill detector will alert designated personnel for immediate response. This will trigger the appropriate planned contingency response action in time to avert catastrophic damage and casualties to wildlife and natural resources.

In this scenario spill detectors may be incorporated into the Area Contingency Plan (such as the ACPs that exist for many designated sensitive areas in California), to provide an early warning defense mechanism that is warranted, but which currently does not exist. As part of any given contingency plan containing advanced spill alert warning capability, designated spill responders would receive a spill alert notification in near real time, allowing them to deploy pre-positioned booms, or implement pre-planned *time-critical* response activities, to protect sensitive habitat such as eelgrass and nesting areas that might otherwise be devastated. Strategic locations for sensor placement would be based on vulnerability analysis or environmental sensitivity index maps (refer to Figure 13). Sensors are also a natural fit and are easily integrated into Geographic Information System (GIS)-based monitoring and response systems, which are of increasing utility for habitat protection, resource monitoring, and contingency planning.

VII. CONCLUSION

The principle of detection upon which this sensor is based is not new science; however, the methodology and application of this technology in the sensor package highlighted in this paper is new. In meeting the initial design goals that were pursued, and having now successfully produced UV/fluorometer-type non-contact spill detection systems that are being used successfully in the real world, this mechanism is being proven of value and utility for a wide range of applications.

At the outset, the goal of developing this new sensor technology was to devise a mechanism to qualify and reliably detect the presence of oil; a discreet Yes or No, Green or Red Alarm; and to sound an alarm whenever trace oil was detected (Yes / Red Alarm!). In numerous instances the sensor has worked as intended and has successfully demonstrated the ability to remotely detect oil and provide an immediate alert. A number of end-user testimonials have surfaced reaffirming this real-world effectiveness, and without naming names, one such a testimonial stated; "we received an alarm at the DCS [Distributed Control System – control center] in the middle of the night. On duty personnel were dispatched to investigate what was presumed to be a nuisance alarm, only to discover that an accidental release had occurred from the facilities'… The spill was contained and problem remedied".

Planned and ongoing improvements to refine and improve this system include continued refinement of the optics in order to obtain performance gains, improved differential signal to noise ratio, and increased detection range. Further to these 'nuts and bolts' system improvements, current designs and packaging are being adapted to meet the demands of 'farther-reaching' applications such as those in the offshore environment (see recent SBM loading buoy deployment, Figure 12) and in the habitat protection scenario suggested above.

A key milestone has been the certification of the sensor technology described in this paper to comply with EPA defined standards. This required successful completion of the US EPA's "Standard Test Procedures for Evaluating Leak Detection Methods".

An even more significant milestone is having now successfully supplied over one hundred systems to date for field deployment. Success with users in real-world applications is always a big step in the progression of developing and introducing new technology products, and the assurance of widespread UV/fluorometry sensor technology implementation to protect against oil spills is growing with each and every early adopter. Many users provide valuable real-world application feedback, plus contribute to broader awareness and acceptance of remote spill sensor technology's use as an environmentally conscientious tool and cost-effective Best Management Practice.

New product features will evolve and new applications will emerge as feedback from end users and regulators continue to drive further development of non-contact UV/fluorometer-type systems. A key component going forward will be to continue to increase awareness of the availability and benefits of new sensor technologies, and to encourage widespread use and adoption of remote spill alarms as well as related spill abatement technologies as integral parts of stakeholders' spill prevention and response strategies. The future is now for utilization of new remote spill detection technology to aid in the prevention and early containment of oil spill pollution.

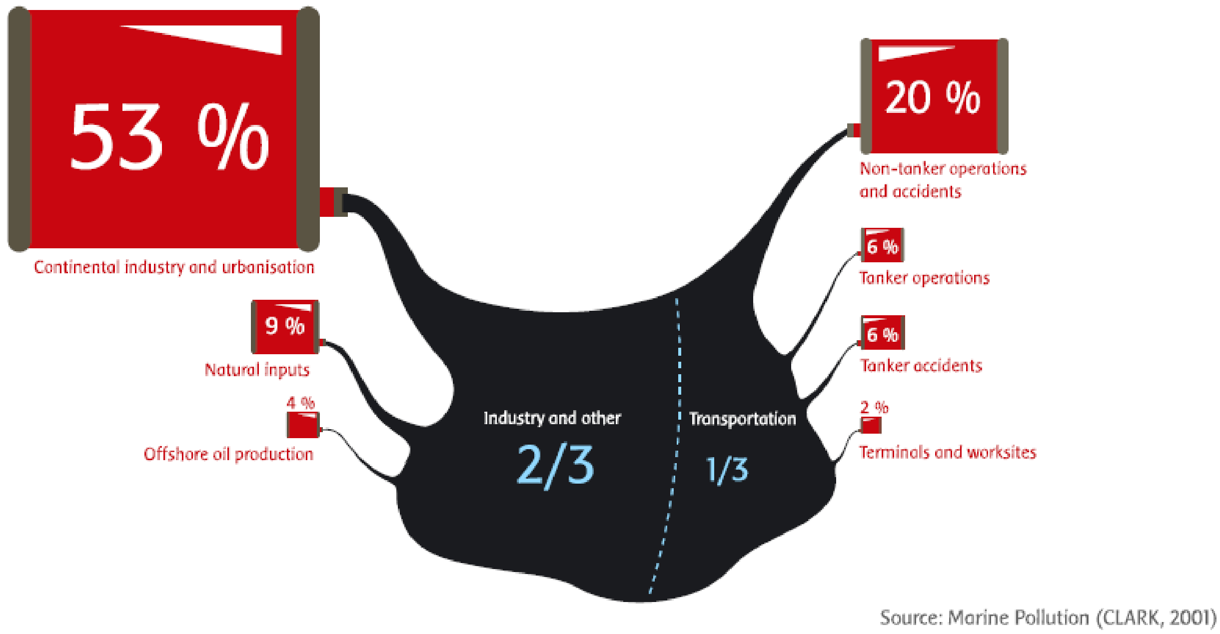

Figure 1. Sources of Marine Pollution (CLARK, 2001)

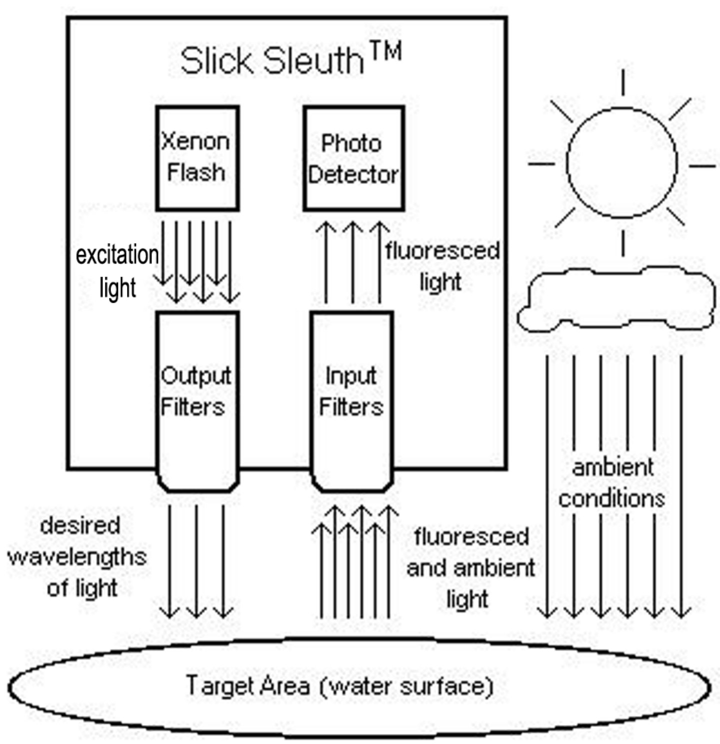

Figure 2. Basic operation of sensor.

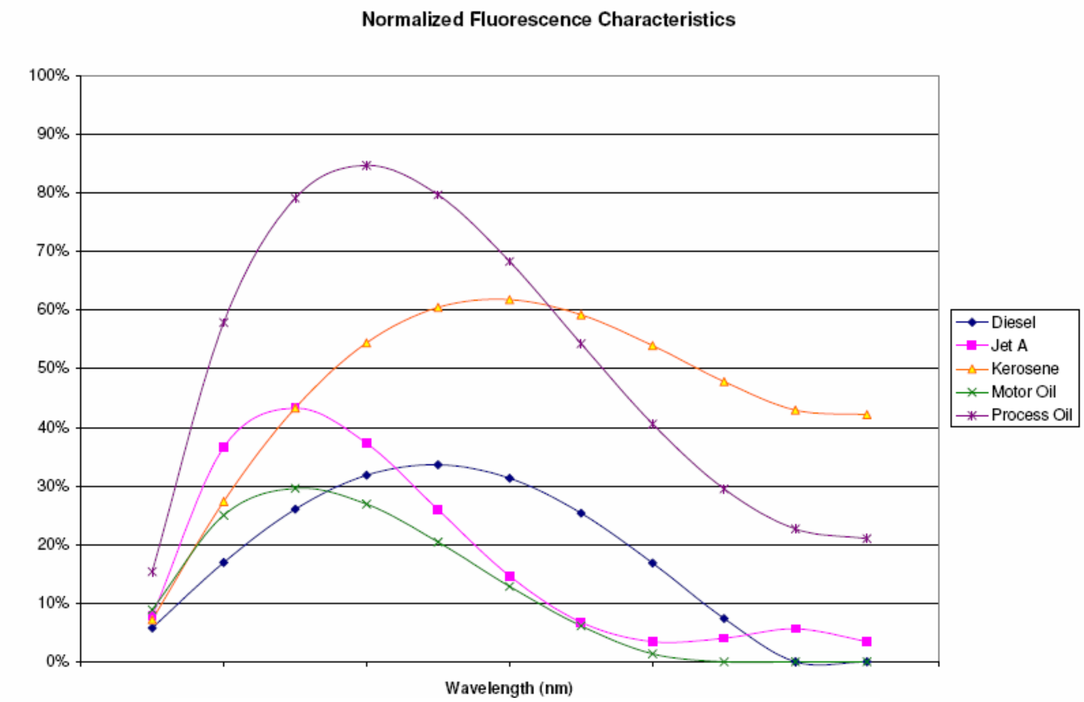

Figure 3. Relative fluorescence of various hydrocarbons

Figure 4. Prototype spill sensor. Installed near fuel pier (background).

Figure 5. Early production unit. DC/Solar power, radio telemetry.

Figure 6. Oil detector operating over stormwater sump. Real time alarm output to nearby control trailer, and automated shutoff of sump outflow/containment valve. *Photo courtesy Dominion.*

Figure 7. One of 6 spill alarm units deployed at a Shell refinery to monitor saltwater cooling outfall channels. *Photo courtesy Shell.*

Figure 8. Unit deployed over deep sump at power plant. Automated control of sump pump for discharge diversion and control. *Photo courtesy Entergy*.

Figure 9. Discharge monitor installed at production facility in the jungle. *Photo courtesy Occidental*.

Figures 10 & 11. Spill sensor installed on fuel pier and marine terminal. Alarm output monitored using SMS messaging to key personnel.
Photo courtesy Royal Australian Navy.

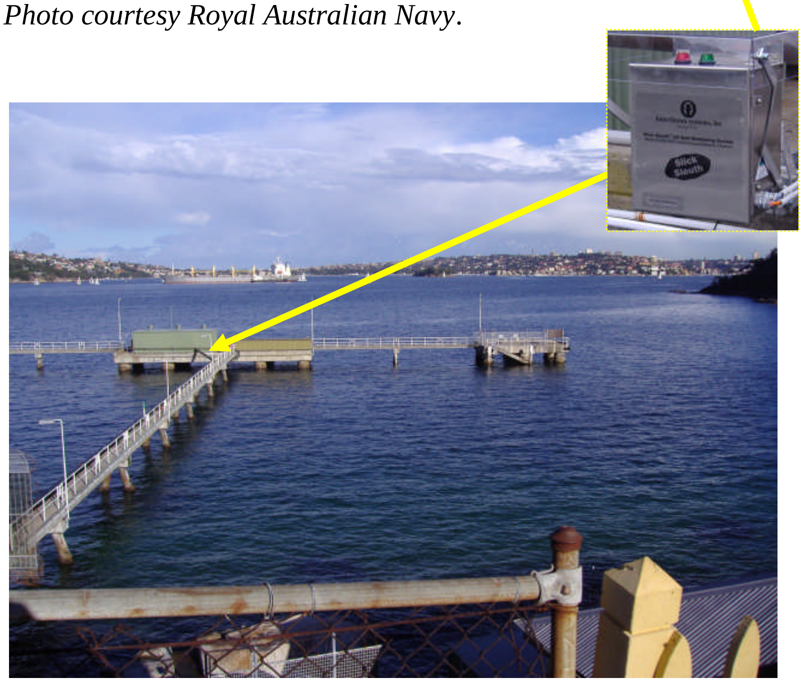

Figure 12. Offshore spill monitor installed on SBM-type 10m loading buoy. Spill alarms signal by radio to shore in real-time from six points on series of three buoys. *Photo courtesy Chinese Petroleum Corp.*

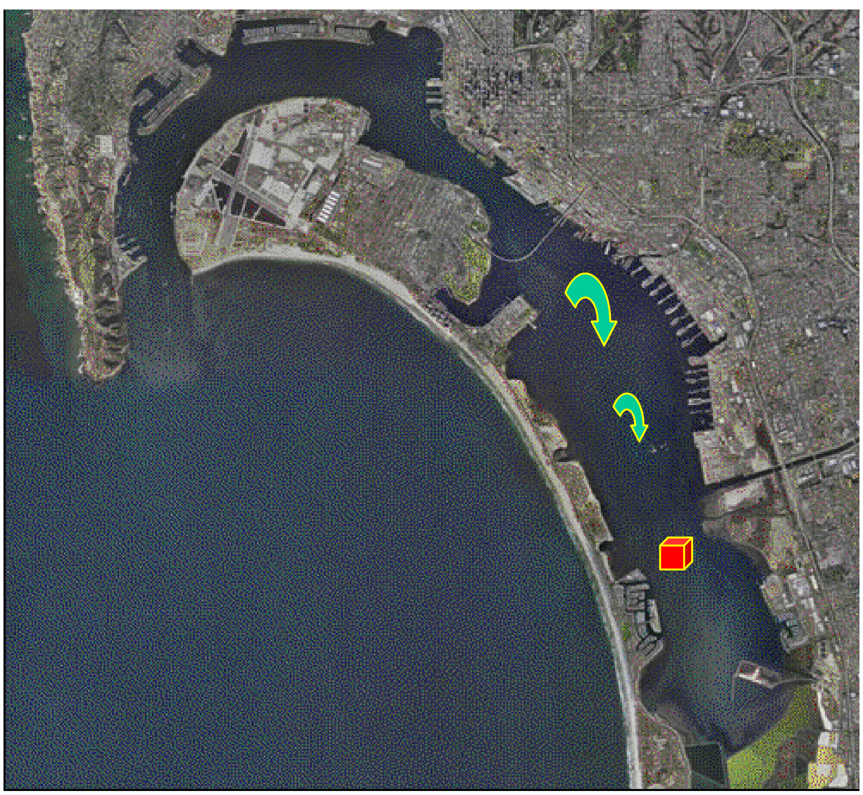

Figure 13. Application concept for deploying spill alarm(s) to early-warning defense and guard against oil spill incursion near environmentally sensitive habitats such as Least Tern nesting grounds and Eelgrass beds. *Photo courtesy Port of San Diego*

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