Subsurface Oil Detection and Delineation in Shoreline Sediments

Phase 2—Final Report

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Executive Summary

The result of a survey of subsurface oil detection and delineation tactics has generated a set of recommendations for studies or activities that have a high probability of success and that could significantly advance this capability at low cost and in a relatively short (1- to 2-year) time frame.

Existing proven technologies have the potential to provide continuous or near-continuous detection capabilities that are both rapid and accurate and that are applicable for a range of shoreline, river bank and terrestrial environments.

To a large degree, the primary obstacles to the acceptance of these proven tactics are that they (a) are poorly understood beyond the teams that currently use these tactics and (b) have not been systematically field tested to provide proof of concept.

This report presents recommendations for the development and testing of emerging, but technically proven, technologies which have demonstrated the potential application to subsurface shoreline, river bank and terrestrial oiling issues. These recommendations have a high probability of success and could become operational tools as there are no technological barriers to overcome.

Recommendations for supplemental work on subsurface oil detection and delineation are identified in Section 4.0.

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1.0 Introduction

Emergency response to oil spills which impact shorelines or river banks is often complicated by the fact that oil may penetrate or become buried in sediment and may not be detectable from the surface. The standard (and current) practice for detection and delineation of subsurface oil on sediment shorelines consists of visual observations made in pits and/or trenches which are either manually or mechanically excavated. This tactic is labor intensive, slow, and because it relies largely on individual (spot) samples, has limited accuracy and efficiency to delineate the horizontal extent of subsurface oil. Adequate delineation is particularly problematic for low oil concentrations, such as scattered tar balls, and irregular oil distribution, such as oil stranded along swash lines. For example, even intensive pit observations might only cover less than 0.01% of an impacted beach and has a high probability of failing to encounter oil, particularly when oil concentrations are low and distribution is irregular. In addition, the relative cost of assessment per sample area (i.e. square yard of pits or trenches dug) is high compared to methods with broader horizontal delineation. Other commonly used tactics such as coring, gas measurement, water jetting, and geophysics also have sample density issues with varying sensitivities to oil and environmental factors which make their performance erratic. The need for faster and more accurate methods for subsurface oil detection and delineation procedures is well recognized. Fortunately, recent and developing technological advances have produced technologies which promise significant advances in subsurface oil detection.

This study was conducted as part of the American Petroleum Institute (API) Joint Industry Task Force Oil Spill Research and Development Program initiated in 2012 to improve, among other aspects of oil spill preparedness and response, the capabilities for Protection and Restoration of Shorelines. One component of this effort focused on the improvement of shoreline survey techniques for the detection and delineation of subsurface oil in sediment shorelines. Phase 1 of this study described current practice in subsurface oil detection and delineation and identified procedures which have been used with varying effectiveness (API 2013: *Subsurface Oil Detection and Delineation in Sediment Shorelines: Phase 1 – Final Report*, API Technical Report 1149-1)[1].

Phase 2 of the study involved: 1) this document presents recommendations for development and field trials of emerging technologies which have demonstrated potential application to shoreline, river bank and terrestrial oiling issues and 2) the production of a field guide (API 2013b: Technical Report 1149-2b)[2] for the application of detection and delineation techniques identified in Phase 1.

2.0 Summary of Phase 1 Findings

2.1 Subsurface Oil Detection and Delineation Procedure Objectives

Evaluation of current and developing subsurface oil detection and delineation procedures was based on the following desired objectives:

- Continuous delineation (both horizontal and vertical dimensions);
- Rapid survey speed (as time typically is of the essence, the procedure should be readily available, adaptable to any sediment shoreline conditions, and include real-time analysis, data processing and plotting capability);

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1 http://www.oilspillprevention.org/oil-spill-research-and-development-cente

2 http://www.oilspillprevention.org/oil-spill-research-and-development-cente

- Characterization of the properties of the oil as necessary to evaluate fate and behavior, including design of a shoreline treatment program; and

- Have low relative cost (including capital investment and operational costs).

Table 2.1 summarizes IDEAL attributes of both existing (current) procedures and for developing technologies which show potential for future application. The evident conclusion from this figure is that no single procedure meets all of the ideal objectives. Attributes associated with each procedure are categorized by color, with green indicating a favorable application, yellow indicating conditional or potential application, and red indicating a procedure that is either “not applicable” or has a low probability of success. In the last row, continuous sampling techniques are colored green and labeled with a capital C; discontinuous (or “spot”) sampling techniques are colored red and labeled with a capital S. Note that the techniques identified in Table 2.1 have favorable application potential that differ from the recommendations given in Table E-1 of the Phase 1 Report[3], due to the ongoing development of the authors’ understanding of the detection techniques.

Costs for various procedures are dependent on numerous unpredictable factors (capital investment, field deployment costs and site conditions being major factors) and are discussed in this report only in relative terms. For perspective, planning level operating costs are all basically within the same estimated range of between US$5,000 to $25,000 per team per day. The field deployment costs do not reflect the survey design differences between techniques which provide continuous areal coverage versus the techniques which involve spot sampling.

Table 2.1—Existing and Potential Attributes of Subsurface Oil Detection and Delineation Procedures

ATTRIBUTES	Existing Procedures			Developing Technology (Potential)			
	Excavate	Cores	Jetting	Push Probes	Detection Dogs	Geophysical	Surface Gas
Delineation (Horizontal)							
Delineation (Vertical)							
Survey Speed							
Oil Character							
Continuous cover (green) vs spot sampling (red)	S	S	S	S	C	C	C

3 http://www.oilspillprevention.org/oil-spill-research-and-development-cente

2.2 Current Practice

The Phase 1 evaluation concluded that current practice for detection and delineation of subsurface oil in sediment shorelines and river banks relies primarily on the use of manually or mechanically excavated pits and trenches to allow visual examination and documentation of subsurface conditions and/or sampling for offsite analysis. Visual examination in pits and trenches, when used with a systematic documentation program, such as SCAT, has generally been adequate to meet operational needs (e.g. Owens et al., 1995). However, these procedures are typically labor intensive, excessively time consuming, and are limited in their ability to accurately and efficiently delineate the 3-dimensional extent of subsurface oiling, particularly in the horizontal dimension. This limitation is largely due to the fact that the excavations rely on discontinuous, or spot, samples which are collected either randomly or on fixed sampling grids. The accuracy of delineations using excavations can be improved through collection of additional samples, but only with additional expenditures of time and resources. Even with an intensive excavation survey, pitting and trenching may only cover a small percentage (<0.1%) of the subsurface area. To a large degree, the selection of sample locations is based on the interpretation by an experienced coastal geomorphologist or sedimentologist of beach morphology and the recent history (typically days to weeks) of beach processes that cause erosion and deposition. This professional judgment in itself does not guarantee that subsurface oil will be detected in the sample locations.

Excavations allow visual examination of sedimentary features so that trained observers can interpret and understand recent physical processes that affect the distribution of oil on a beach. Sedimentary features include beach stratigraphy, location and character of depositional zones, nature of penetration of fluid oils, and the location of groundwater levels, all of which are important to understand the depositional environment and in planning and implementing tactical response actions. Excavation and visual observations in some form (trenches are usually most effective) are required to understand the character and vertical distribution of subsurface oil, collect data, and samples, if necessary. Excavation in some form is likely to be required for verification and calibration of many of the developing subsurface oil detection and delineation procedures.

Other procedures, including coring and water jetting have been used historically with varying degrees of success. These procedures also rely on collection of limited point source information, and, although they share similar limiting characteristics and limitations with excavations, they are typically more time consuming. A few of the more novel procedures include:

- Gas measurements have seen limited use on shorelines historically, and, although their use has been promising, no satisfactory field instrumentation has been available and off site laboratory analysis was required, rendering the procedure impractical for emergency response. Advances in field instrumentation, GPS, and analytical software have led to the development of real-time gas monitoring bundles that show promising application to emergency oil spill response.

- Applicable geophysical techniques have been available for at least 20 years, and have been applied successfully to many onshore oil and hazardous material investigations, but have rarely been applied to shoreline situations. In general, geophysics lacks the sensitivity for detection of small quantities or scattered distributions of buried oil, and some tactics are subject to interference by salt water.

2.3 Developing Technology

A number of developing procedures and technologies were identified in the Phase 1 study. These procedures and technologies as described below have the potential to significantly advance current practice, under conditions where their use is appropriate.

2.3.1 Detection Dogs

Description:

Detection dogs are a proven strategy in common use worldwide to detect and locate a wide range of materials including drugs, explosives, contraband food shipments and missing persons. Their importance in certain fields, particularly the detection of narcotics, led to the formation of a US federal government funded Scientific Working Group on Dog & Orthogonal Detector Guidelines (SWGDOG)[4]. This group was established to develop consensus based best practices for the use of detection teams). SWGDOG is a partnership of local, state, federal and international agencies including private vendors, law enforcement and first responders. The group has completed ten approved Guidelines for Best Practices[5] which provide in-depth descriptions of dog and handler selection, training, team assessment, certification, maintenance training, and documentation. Among others, guidelines which may provide useful benchmarks for developing petroleum detection and delineation tactics include:

Dog Selection (SWGDOG SC 3)

- Screening: aptitude, temperament, and health evaluation
- Tracking evaluation
- Training and vendor responsibilities

Selection of Handlers (SWGDOG SC 5)

- Qualifications: personality, experience
- Training (theory and practice): curriculum
    - Safety
    - Canine care and health
    - Obedience
    - Search techniques
    - Proficiency training
    - Learning and conditioning
    - The senses, properties of scent, drive, response and character traits

In the US the role of detection dogs is also recognized by:

- Military Working Dog programs and Manuals of the armed forces (e.g. Army, Navy, etc.);
- USDA National Detector Dog Manual that defines procedures, health care and training of detection dogs (UDSA, 2012);

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[4] http://swgdog.fiu.edu/about-us/history__goals_of_swgdog.pdf

[5] http://swgdog.fiu.edu/approved-guidelines/

- Auburn University Canine Detection Institute's Olfactory Detection Behavior Laboratory in the School of Veterinary Medicine; and

- Government (non-military) training centers that are maintained by the USDA (National Detector Dog Training Center, Newnan, GA), the DoJ ATF (National Training and Operations Center, Front Royal VA) and the USDHS (Customs and Border Patrol Canine Centers, Front Royal VA and El Paso TX).

Specific field tests to detect oil were conducted in Svalbard (Dickins et al., 2010), funded in part by MMS-BLM (now BOEMRE), and in January 2007 following the M/V *Server* oil spill (Buvik and Brandvik, 2009). These tests demonstrate the ability and extreme sensitivity of a Detection Dog Team to detect and locate subsurface hydrocarbons, sometimes at considerable distances. Detection dogs also are successfully used commercially to detect natural gas and liquid petroleum leaks from buried pipelines[6].

In evaluating the performance and potential of Detection Dogs it is important to distinguish between the ability to "detect and locate" and to "delineate". Detection dogs are generally trained to detect and locate specific materials. Their detection sensitivity is remarkable and detection levels of parts per trillion are reported[7] and they are capable of detecting a very wide range of hydrocarbons. Location is achieved by sensing and following airborne concentration gradients to their source or point of high concentration. This information is valuable, particularly for leak detection and location. However, oil which has penetrated or has been incorporated in shoreline or river bank sediments may range from extensive low concentrations to continuous, discontinuous or irregular layers, or scattered tar ball size deposits.

Possible limitations in the delineation of the horizontal extent of buried oil could be related to the process by which a dog senses the oil. As some level of air circulation is normally present above the sediment surface the oil vapor detected by the dog at a given point may have a local or an upwind source, and may or may not be indicative of the presence of subsurface oil at that point of detection. If it is assumed that dogs can sense gradients, then it should be possible for the handler to interpret the behavior and/or develop search protocols to provide delineation of the horizontal extent of buried oil. Test data reviewed in Phase 1 does not conclusively support this capability and additional development work on this topic is recommended.

Accurate delineation of both the vertical and the horizontal extent of subsurface oil are necessary for designing and monitoring a successful shoreline treatment program. Detection Dogs can detect hydrocarbons in the air above the shoreline or river bank surface emanating from subsurface oil but vertical delineation must be conducted by other means (pits, trenches, push probes, etc.).

A Detection Dog Team would be part of the shoreline assessment survey program and work with SCAT (Shoreline Cleanup Assessment Technique) Team Leaders to develop a survey design that would focus, a least initially, on areas where oil potentially could have been buried or penetrated into the subsurface sediments.

At the current state of development, Pros and Cons regarding use of Oil Detection Dog Teams are summarized below:

<u>Pros:</u>

- Dogs have been used for gas and liquid pipeline leak detection, using an injected odorant or specific oil calibration.

- Little training time would be required for an experienced detection dog/handler team, even with no prior oil detection experience, as a "match the sample – sniff and search" technique can be applied.

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6 http://www.detectordogservices.com/oil%20and%20gas%20services.html
7 http://www.pbs.org/wgbh/nova/nature/dogs-sense-of-smell.html

- The use of dogs is several orders of magnitude quicker than manual digging or augering:
  - In one day, manual digging by a single team has a maximum production of 200 pits (based on MC 252 field operations): with two teams this translates to 3–4 linear miles coverage with 3 pits across-shore per 100 yard interval transect and a TOTAL “SAMPLE” OF 100 sq. yds.
  - In one day, a pair of detection dog teams can cover up to 2–3 linear miles of continuous coverage which equates to a TOTAL “SAMPLE” OF 100,000 sq. yds (estimate by E. H. Owens, 2013).
  - Dogs provide virtually 100% coverage versus <0.01% coverage by manual or auger spot sampling (estimate by E. H. Owens, 2013).
- A pit or trench sampling design is only applicable for continuous layers of buried or subsurface oil (e.g. Tampa Bay spill 1993 – Owens et al., 1995). If the oil is discontinuous, designs with an interval of 3 pits every 100-m is a “hit or miss” approach with a very low probability of detecting either large mats or discontinuous subsurface oil.
- Dogs can be trained to detect different types of hydrocarbons at extremely low levels.
- Costs for trained dog/handler teams are currently moderate in comparison to some existing practices. These costs are expected to drop to the low-moderate range as more geographically diversified teams are identified.
- Dogs and/or handlers can be equipped with GPS units to facilitate tracking, data collection and data reduction/plotting.
- The procedure can be applied on most sediment shorelines and on land.
- The tactic has minimal environmental impact, with the possible exception of some potential wildlife disturbance.

<u>Cons:</u>

- Dog surveys do not delineate the vertical distribution of oil.
- The ability of dog/handler teams to delineate horizontal subsurface oil distribution needs additional evaluation.
- Detection levels in terms of amounts of oil and scattering should be further evaluated.
- The ability of a dog team to detect subsurface oil beneath overlying oil layers or beneath vapor plumes from upwind sources has not been evaluated.
- Vertical delineation of oil requires physical sampling and/or observations (by excavation, coring, push probes, etc.).
- The geographic availability of commercial detection dog teams and handlers in the United States and Canada has not yet been evaluated.
- Search capabilities and the temperament of different breeds of dogs are different.
- Calibration and periodic confirmation of survey findings would be required.

A representative oil search by a trained dog and handler is shown in Figure 2.1.

Figure 2.1—Oil Detection Dog and Handler at Work (SINTEF)

2.3.2 Hydrocarbon Gas Detectors

<u>Description:</u>

Hydrocarbon gas measurement has been evaluated for many years as a tool for oil exploration and leak detections (Horvitz, 1972, 1986; Hunt, 1981; Jones et al., 1999; Jones and Drozd, 1983). Procedures used required physical collection of samples and their analysis at an offsite laboratory. Spot sampling and analysis turn-around times significantly degraded the application of these tactics for emergency response use.

Advances in technology in the last 10 years offer continuous real-time near-surface hydrocarbon gas data collection and data processing packages, which include GPS positioning and mapping. Monitoring packages are offered which can be operated from aircraft and surface vehicles, including all terrain UTVs. Most of the systems offered are designed for methane detection using spectroscopy, although heavier volatile organic carbons can also be detected. Testing of gas monitoring for crude oil detection in and under ice conducted on lightly weathered crude oil spilled on ice at the Svea test site in Norway as part of the Joint Industry Oil in Ice Project indicated that methane emissions were detectable on the surface and at concentrations high enough to at least theoretically be detectable from the air (Dickins et al., 2010;

Hirst and O'Conner, 2010). Other Joint Industry Oil in Ice tests demonstrated successful ethane measurement through using a technology developed by Shell (Dickins et al., 2005). The ethane tests also demonstrated the potential to detect ethane at considerable distances from the source.

Use of methane and ethane emissions as an indicator of spilled oil on shorelines is of questionable use for all but relatively fresh oil due to the volatility of these materials (note: volatilization rate for lighter hydrocarbons from emulsified, buried or encrusted oil may be increased). Nonetheless, the capability of existing instrumentation will allow detection of hydrocarbons heavier than methane and ethane. Some of this instrumentation is also capable of measuring other materials which may be indicative of hydrocarbon degradation (CO_2) and presence of sulfur compounds (H_2S) in some crudes.

A number of instrument and service providers are currently offering hydrocarbon (gas and liquid) leak detection services based on multi-gas detection which use propriety instrumentation, including Cavity Ring-Down Spectroscopy and traditional IR Spectroscopy on mobile platforms. One of these services reports the ability to monitor for "total hydrocarbons", which should allow detection of considerably heavier molecular weight hydrocarbons. In addition, the ability to monitor multiple parameters simultaneously extends the potential for this developing tactic.

As with Detection Dog Teams, equipment of this type measure surface gases and do not discriminate subsurface oil location or character vertically. Unlike dogs, the instrumentation generally produces quantitative data. The ability to detect small quantities of scattered subsurface oil, such as buried stained sand or tar balls, has not yet been evaluated. Confirmation and/or calibration sampling would be required as this procedure does not provide vertical discrimination

Mobile hydrocarbon detection sensors have been developed which can be mounted on ATVs for shoreline application. These units collect gas samples at the shoreline surface and are capable of simultaneous multi-parameter detection (methane, CO_2, total HC, H_2S, and others) to sub part-per-million levels. Equipment and services of this type are currently offered for gas and liquid hydrocarbon pipeline leak detection.

For this technology there are three primary issues of importance:

- Gas measurement has been shown to be effective for detecting and locating lighter hydrocarbons. The ability of existing instrumentation to detect heavier gases associated with spilled oil, and in particular weathered oil, is promising, but needs additional evaluation.
- As with the use of dogs, near-surface gases are subject to wind dispersion and may or may not indicate the presence of subsurface oil at the location of measurement.
- The sensitivity of the tactic for detection of small amounts of scattered subsurface oil needs to be evaluated.

At the current state of development, Pros and Cons regarding use of Gas Detection are summarized below.

<u>Pros:</u>

- Potential to provide continuous horizontal detection and delineation – can be mounted on ATV.
- Can provide real-time quantitative data.
- Can be equipped with multiple sensors (including methane, CO_2, THC, H_2S and others).

- Minimal training required to operate.
- Available technology that is becoming more readily available.
- Procedure can be applied on most sediment shorelines.
- Minimal environmental impact.
- Cost low to moderate.

Cons:

- Does not discriminate oil vertically.
- Low level sensitivity and ability to detect heavy/weathered oil needs further evaluation.
- Requires calibration and confirmation sampling.
- Different oils will have different light ends and therefore different sensitivities.
- Weathering of oil will change the volatile components and affect sensitivity.

A typical ATV installation is shown in Figure 2.2.

Figure 2.2—Mobile Gas Detector Mounted on ATV (Apogee Scientific)

2.3.3 Push Probe Technology

Description:

Push probe technology is used in hazardous waste remediation and utilizes small diameter probes which are pushed or driven into unconsolidated sediments. The probes can be equipped with multiple sensors which can collect continuous soil, soil gas, and groundwater samples and can simultaneously collect geophysical (resistivity and conductivity) and geochemical (BTEX and Petroleum Hydrocarbons) data, penetration resistance, UV fluorescence and video and still imagery. Geo-positioning and data analysis/plotting packages are available. Sampling equipment can be mounted on small ATV equipment or in larger sampling vehicles which may include instrumentation and data processing enclosures. This technology is in common use for hazardous material investigation. A comprehensive description of the technology is available from the Ohio EPA, Technical Guidance for Ground Water Investigations (Ohio EPA, 2005).

At the current state of development, Pros and Cons regarding use of Push Probe Technology are summarized below.

Pros:

- The technology is typically capable of continuous vertical sampling to 5 meters using lightweight equipment which can be mounted on all-terrain or larger vehicles.
- Collects quantitative data, and may provide an alternate to pits and trenches for calibration and monitoring of remote sensing tactics.
- Real-time data processing and presentation packages are available.
- Push probe observations are quicker and more comprehensive data collection than sampling using conventional coring devices.
- Minimal environmental impact.

Cons:

- Collects spot samples.
- Sampling rate for horizontal delineation is slower than pit excavations.
- Specialized equipment and operators are required.
- Procedure may be limited by shoreline access and traffic ability.
- Survey costs are anticipated to range from moderate to high.

A representative small push probe unit is shown in Figure 2.3.

Figure 2.3—Small Push Probe Unit

2.3.4 Geophysical Techniques

Potential geophysical technologies include:

- Ground Penetrating Radar (GPR);
- Electromagnetics (EM) profiling or Terrain Conductivity; and
- Electrical Resistivity (ER) Profiling.

These technologies are mature, in the sense that they have been in use for various applications for many years, but have not been extensively tested or applied to shoreline subsurface oil detection and delineation. Trials that have been conducted on subsurface shoreline oil indicate that they are sensitive to case-specific conditions and are in general appropriate for thicker, continuous deposits of oil and not applicable to small quantities of oil, such as thin discontinuous deposits or tar balls. Some techniques are sensitive to the presence of salt water. Depth resolution is variable and confirmation and calibration using pit or trench observations likely would be required. The following procedures were identified as having potential use in the detection and delineation of subsurface oil in sediments.

Ground Penetrating Radar (GPR)

Description:

Ground penetrating radar transmits electromagnetic energy (high frequency radio waves) into the ground. A reflected signal is recorded by the receiver in the instrument and images of the sedimentary structure are created if these waves encounter subsurface objects or layers of contrasting material. Ground contact on as flat a surface as possible is required to avoid signal disruption. Penetration is highest in dry sandy soils and ice. Presence of clay and water, in particular salt water, may interfere with the operation of the equipment, which, for marine shorelines, basically limits use of this technique to upper backshore areas (which are common locations for oil deposition).

GPR was used successfully in the upper intertidal zone during the 2002 T/V *Prestige* oil spill response to detect small (1 cm or less) discontinuous oil layers (Lorenzo et al., 2004, 2009). The technology is in common use for cultural resource surveys and sand resource surveys.

GPR units for use on beaches commonly are equipped with large wheels or mounted on skids which can be towed to compensate for surface irregularities. Representative units are shown in Figure 2.4.

At the current state of development, Pros and Cons regarding use of Ground Penetrating Radar are summarized below.

Pros:

- Rapid continuous horizontal discrimination.
- Limited depth discrimination.
- Requires one or two trained operators.
- Equipment and operators available from geotechnical service companies.
- Positioning and plotting software available.
- Procedure can be applied on most sediment shorelines.
- Minimal environmental impact.
- Low cost.

Cons:

- Not sensitive to small quantities or scattered oil in shoreline sediments.
- Salt water interference common so that use typically would be restricted to upper intertidal and supratidal zones.
- Trained operator required.
- Calibration/confirmation sampling would be required.

Figure 2.4—Representative Skid-mounted GPR and Wheeled Configurations

(Source: **l.** www.gly.fsu.edu/~donoghue/activities.htm **r.** www.du.edu_CRWPKGQ8)

Electromagnetic (EM) Profiling

Description:

Electromagnetic profiling, also known as Terrain Conductivity, is based on mapping the variations in the electrical conductivity in shallow sediments using the principal of induction. Oil is electrically resistive in comparison to sediments which exhibit varying degrees of conductivity related to grain size, moisture, salt content, and other factors. Layers of non-conductive oil or oil-saturated sediment, if in sufficient quantity, may provide sufficient contrast to be detectable. Confirmation/sampling is required for calibration and resolution of potential false positive observations.

EM profiling is unlikely to be suitable for the detection or delineation of scattered or discontinuous amounts of subsurface oil or tar balls. The technique has been proven successful for onshore detection of shallow subsurface deposits of petroleum hydrocarbons (Saunders et al., 1983, 1987). EM profiling is a very rapid, non-contacting procedure which can be conducted at low cost by one or two operators. Real-time data processing and plotting packages are available.

At the current state of development, Pros and Cons regarding use of Electromagnetic Profiling are summarized below.

Pros:

- Rapid survey non-contacting technique.
- Continuous horizontal discrimination.
- Limited depth discrimination.
- Positioning and plotting software available.
- Procedure can be applied on most sediment shorelines.
- Minimal environmental impact.
- Low cost.

Cons:

- Not sensitive to low concentrations or scattered oil.
- Trained operator required.
- Calibration/confirmation sampling required.
- Needs a difference in electrochemical signature, so not effective with all soils.

A representative EM or Terrain Conductivity device is shown in Figure 2.5.

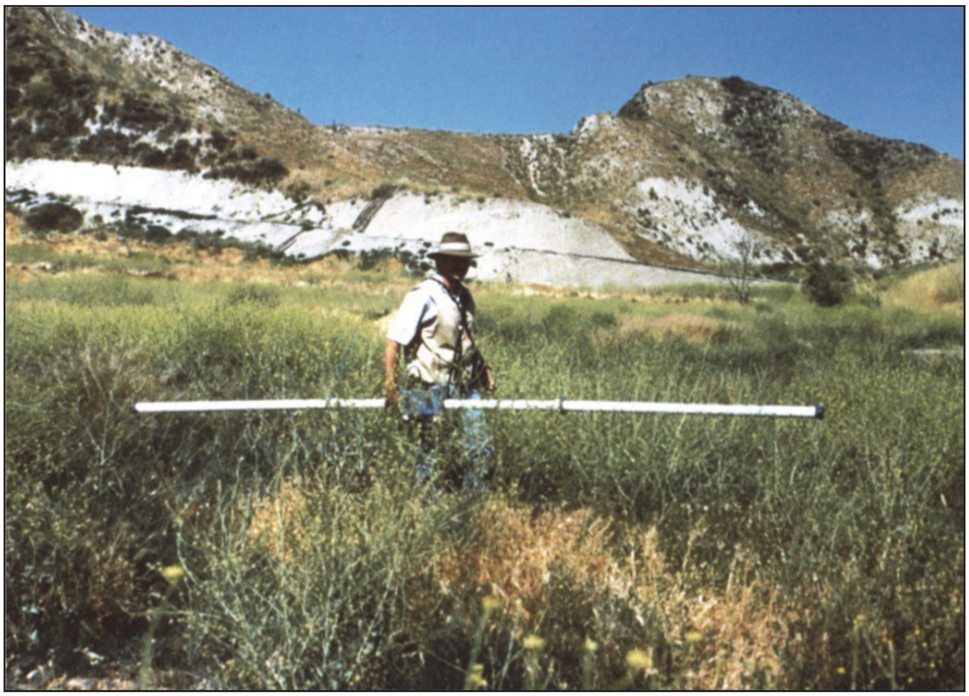

Figure 2.5—Representative EM/Terrain Conductivity Instrumentation

Electrical Resistivity (ER) Profiling

Description:

ER profiling measures the ability of shallow subsurface sediments to pass electrical current. Layers of oil or oil-saturated sediment are typically resistive to electrical current and can contrast sharply with natural materials, if in sufficient quantity and continuous distribution. The technique is normally applied by using electrodes driven into the sediment, inducing an artificial electric field and measuring voltages across the electrodes. For shoreline use, an array exists that does not require fixed electrodes and which can be towed across the surface manually or by an ATV. Extremes in resistivity may result in instrumental interferences or create false positives (such as presence of freshwater). As with all geophysical tactics, confirmation sampling should be conducted to confirm readings and calibrate equipment. As with other geophysical methods, successful detection and delineation of scattered tar balls and low concentrations or discontinuous deposits of oil is unlikely. The technique's best potential is for detection and delineation of larger continuous oil deposits. Observations for conformation and calibration would be required.

At the current state of development, Pros and Cons regarding use of Electrical Resistivity Profiling are summarized below.

Pros:

- Rapid survey technique.
- Continuous horizontal discrimination.
- Positioning and plotting software available.
- Equipment and operators available from geotechnical survey companies.
- Procedure may be applied on most sediment shorelines.
- Minimal environmental impact.
- Low cost.

Cons:

- Not sensitive to low concentrations or scattered oil deposits.
- Trained operator required.
- May produce false positives.
- Calibration/confirmation sampling required.
- Minimal depth discrimination (if any).

A typical towed ER array is shown in Figure 2.6.

3.0 Findings and Conclusions

The key findings of the study include:

- Accepted procedures for detection and delineation of Subsurface Oil in Sediment Shorelines have not changed appreciably in the last 40 years;
- Existing procedures, when used with a systematic descriptive program (such as SCAT) can provide useable operational information on the depth, horizontal extent, and character of subsurface oil, but at considerable, and occasionally unacceptably high, expenditure of time and effort. Because of this, more efficient and expeditious procedures are highly desirable;
- No current or identified developing procedures for subsurface detection and delineation have been identified that meets all of the ideal survey objectives. To provide the flexibility necessary to respond to a broad spectrum of oil types, levels of oiling and environmental conditions**, a variety of tactics and equipment would be required to support emergency response operations** (including trained operators);
- Developing technologies promise significantly faster and more accurate detection and delineation of subsurface oil, particularly in the horizontal dimension, and include GPS positioning and real-time analysis and plotting capability. Some procedures may be capable of detection and delineation of low concentrations of oil and discontinuous distributions, whereas others are limited to greater concentrations and more regular distributions.

Figure 3.1—Towed Electrical Resistivity (ER) Array

4.0 Recommendations

Phase 1 has identified a number of procedures and technologies that promise to significantly improve emergency response capabilities for the detection and delineation of oil buried in sediment shorelines. Many of these procedures are ready for field trials, but some would benefit from additional development efforts. The recommendations for further development and/or testing of selected techniques are summarized in Table 4.1 with additional detail provided in Sections 4.1 – 4.5. The recommendations have been priority ranked 1, 2, or 3 (i.e. lower numbered projects should be considered first) so that as future funding becomes available, API and other organizations will know the general order in which these projects should be implemented.

Table 4.1—Summary of Phase 2 Recommendations

TOPIC	RECOMMENDATION	ACTIVITY	PRIORITY
Detection Dog Teams DD-1	Create a Handbook for Spill Managers on the Role of Detection Dog Teams in Subsurface Oil Detection and Delineation	Collate and summarize the existing state-of-knowledge for use of detection dogs by SMTs, including SCAT managers, to understand the advantages and limitations of detection dogs for shoreline oiling assessment surveys.	1
Detection Dog Teams DD-2	Develop Training Materials for Detection Dog Team Providers, Trainers and Handlers	Develop a standard training course for services, trainers and handlers to understand how detection dog teams fit into shoreline oiling assessment surveys: this would include sections on spill response management, shoreline oiling assessment/SCAT surveys, shoreline processes and sedimentology, and stranded oil behavior.	1
Detection Dog Teams DD-3	Evaluate Shoreline and Terrestrial Horizontal Delineation Capability	Define the expectations of a detection dog survey in terms of (a) the types of subsurface deposits Dog Teams would be expected to locate and (b) how the Teams would delineate oil (search patterns).	1
Detection Dog Teams DD-4	Applications to Terrestrial and River Oil Spills	Currently dogs are used to detect pipeline leaks by placing an odorant in the line. Field tests can determine whether this odorant necessary or not. Field trials can also determine whether dogs can detect oil under water, for example in streams or rivers.	1
Gas Measurements GM-1	Oil Detectability	Bench-scale tests to determine what current instrumentation can detect in terms of oil types, including weathered oils.	1
Gas Measurements GM-2	Sampling Intakes	Potential design of sensor intake systems to better conform with ground topography at fixed levels above the surface.	2
Gas Measurements GM-3	Detection Levels	Bench-scale tests to define threshold concentrations that can be detected by the instrumentation.	2
Push Probes PP-1	Field Trials	Field trials and demonstrations on Spills of Opportunity.	2
Geophysical Techniques GT-1	Field Trials	Field trials and demonstrations on Spills of Opportunity.	2
Spills Of Opportunity SOO-1	Demonstrations and Field Trials	Demonstrate of test promising tactics and equipment on actual spills.	1

4.2 Detection Dog Teams – DD

As a result of their proven detection/location capability and potential for delineation, the use of oil-trained Detection Dog Teams is assigned a higher priority for further development. Three specific recommendations are:

Recommendation DD-1: Guidance Manual for Oil Spill Managers/Responders

- The current, general, low level of awareness regarding the potential use of Detection Dog Teams as part of a shoreline oiling assessment/SCAT program to detect and delineate subsurface oil in sediments limits the use of this tactic.
- The Manual is designed to raise the level of awareness of the potential benefits of the tactic to the oil spill response community.
- The study would include:
  - a summary of the state-of-knowledge,
  - guidance on known existing capabilities and limitations,
  - guidance on how to design a Detection Dog Team survey within a SCAT program, and
  - information on criteria that could be used in the selection of providers.
- The Manual is intended for use by decision makers regarding the appropriateness of a detection Dog Team survey and the tactical implementation of a survey design.
- This Manual would be based on current knowledge and experience and would not involve field or other trials.
- How to integrate into SCAT.

Recommendation DD-2: Training Manual or Handbook for Detection Dog Providers

- The current detection dog providers are not part of the oil spill response community and this training document is designed to provide an understanding of the potential role of Detection Dog Teams in a response.
- The development of a standard training course for Detection Dog Team providers, trainers and handlers would focus on those aspects of oil spill response management, shoreline oiling assessment surveys, shoreline processes and sedimentology, and stranded oil behavior that would be important in creating a Detection Dog capability for deployment on a spill response.
- The oil-trained Detection Dog community is currently very limited in both numbers and geographic location. Although Detection Dogs have been used for pipeline hydrocarbon leak detection in the United States and Canada, the only known experienced oil spill search trainer/handler Subject Matter Experts are located in Trondheim, Norway. However, individuals involved with detection dogs indicate that little training time would be required for an experienced detection dog/handler team, even with no prior oil detection experience, as a “match the sample – sniff and search” technique can be applied.
- More resources are necessary for detection dog teams to become a realistic survey technique and it should be possible for existing detection dog providers to train themselves and their dogs for

subsurface oil detection surveys. This training material would provide them with the information necessary to understand the objectives and purpose of subsurface oil detection and delineation and to use that information to develop in-house capabilities.

- The materials would address the appropriate attributes of a detection dog, as breed is an important consideration in training and handling.

- Existing detection dog providers have limited experience regarding oil spill behavior and information needs and objectives. Knowledge in these areas is believed to be essential for maximum effectiveness of this tactic. Development of a standardized oil spill training curriculum for trainers/handlers so that they could more easily integrate within the shoreline oiling would enable them to train within the context of expectations during a typical assessment survey and to more easily integrate within that program.

- It is recommended that the training materials could address the following topics:

  - Purpose and use of detection dogs
  - Characteristics and selection of an oil search dog
  - Dog trainer expectations and support requirements
  - Needs and expectations of the Spill Management Team (including data/ documentation needs and time frames
  - Training requirements
  - Search patterns
  - Subsurface oil survey and detection dog team case studies
  - Spill management
  - Oil fate and behavior
  - Shoreline sedimentary processes and environmental factors
  - The SCAT principles, definitions and process
  - Shoreline treatment tactics and information requirements

Recommendation DD-3: Evaluate Horizontal Delineation Capability

- This recommendation is based on the requirement to better understand and clarify the ability of Dog Detection Teams to locate subsurface oil concentrations and the ability to delineate the spatial extent of oil deposits in shoreline and terrestrial environments.

- This recommendation aims to define the expectations of a Detection Dog Team survey in terms of (a) the types of subsurface oiling conditions that Dog Teams would be expected to locate, and (b) how the Teams would delineate oil (search patterns).

- A Detection Dog Team could operate in a range of survey modes. In particular, current options are that a Detection Dog Team could locate:
  - a continuous subsurface oil location or a boundary and then spot sampling (pits, augers, trenches, probes etc.) would delineate the horizontal and vertical dimensions, and/or
  - discontinuous subsurface oiling that would be separated by non-oiled sediments: in which case a specific reasonable separation target distance should be defined (for example, 5m, 10m or greater): again, horizontal and vertical dimensions would be defined by spot sampling, and/or
  - small scattered subsurface oil deposits, including tar balls.
- It is not clear that these important distinctions have been recognized in the design of test programs or in the training of dogs and their handlers. Detection dogs are typically trained to find a specific material (or in the case of oil, a high concentration) at the end of a trail rather than to delineate zones. It is believed that dogs in general have the necessary information to delineate, and it may be possible to delineate the extent of oiled areas using any of the following:
  - Interpretation of the search behavior as a dog passes over edges and concentration changes. Changes in subsurface oil concentrations are typically abrupt and at subsurface oil/non-oiled boundaries either the dog would indicate the change by a physical action, such as stopping movement and/or sitting at the boundary, or the behavior of a dog would be recognized by the handler;
  - Additional training to recognize and react to abrupt concentration changes; and
  - Use of carefully designed search patterns.
- A range of limited field trials with different weathered oil types would provide an information base and accuracy limits that could be used to guide the decision on whether the Detection Dog survey option is appropriate for a given situation. Such field trails could be small in scope yet provide a better understanding of the opportunities and limitations of a Detection Dog survey.

Recommendation DD-4: Evaluate Terrestrial Applications for Detection Dog Teams

Two related recommendations are for issue-oriented field trials. These would be conducted under controlled conditions, and not on public lands, to evaluate specific application of the Detection Dog tactic for shoreline, river bank and terrestrial spills.

A. PIPELINE LEAKS

Currently dogs are used on a limited commercial basis to detect pipeline leaks on land by placing an odorant in the line and using a “match the sample” tactic.

- A set of replicated field tests within a trial can determine whether this addition is necessary or not for a range of oil types. Oils in pipelines contain light fractions that escape only when a line leaks or ruptures. Dogs should be able to detect these easily for above ground lines or spills into rivers and streams and also for oil within soils.
- Each test takes very little time to set up and conduct (minutes-hours) and results are immediate. It is possible to carry out a range of tests in one day and to replicate these with separated Detection Teams for proof of concept.

B. SUNKEN OR BURIED OIL UNDER WATER

- Field trials can also be used to evaluate the degree to which dogs can detect oil under water, for example in shallow marine waters or lakes and in streams or rivers.

- An informal field trial has demonstrated the ability of a dog to detect oil buried in sand in shallow (0.5 m) water on a tidal beach.

- Commercial ship-based towed hydrocarbon gas detectors ("sniffers") have been deployed above the sea bed since the early 1980's to detect offshore gas seeps (Jones et al., 1999). It is reasonable to assume that dogs, which have a more sensitive sensor than these underway monitoring systems, should be able to detect gas from sunken at the surface in the same way.

- In particular, this tactic could be valuable for shoreline or river bank surveys where the sunken oil is in the immediately adjacent water.

- Field trials in controlled conditions, such as tanks or lined pits on private lands, could present increasing water depths and a variety of oil types and concentrations to evaluate the potential range and the limits of detection dogs for this type of survey. The application for this type of detection dog tactic would be:

  - sunken oil in marine or lake nearshore shallow water sediments;

  - sunken oil in river or stream bed sediments in moving waters; and

  - oil that has spilled underground within or below the water table.

4.3 Gas Measurements

Available new technology shows promise for real-time continuous delineation of subsurface oil using instrumentation capable of detection of vapors, including heavier hydrocarbons. The process is similar to the use of detection dogs and shares many of the same unknowns, with the following exceptions:

- Detection levels for instrumentation are not as low as for dogs (ppm vs. ppt).

- Instrumentation can be calibrated and standardized.

- Gas measurements are quantifiable and plotting observed gradients is possible and may be constructive in subsurface delineation.

Recommendations for additional development work include the following:

Recommendation GM-1: Oil Detectability

Evaluation of the capability of instrumentation to detect a range of oil types and different weathered oil using simple bench scale measurements should be conducted. The development of a standardized test protocol is recommended, including use of standard test oils, to permit repeatability and comparison between different instrumentation. Oil types and treatments are suggested in Table 4.2.

Table 4.2—Suggested Test Oils and Treatments

Oil Type	Fresh	Emulsified	Weathered
LA Light Crude (Paraffinic)	x	x	
ANS Crude (Asphaltic)	x		x
FO 380	x		x

These oils should be readily available from industry sources, precluding the need for a central test oil repository. Protocols could be developed for emulsification and weathering treatments. Test samples should be relatively small (50 ml) so that only small volumes of test oil would be needed.

Testing could be performed by industry, industry contractors or voluntarily by instrumentation vendors. Voluntary vendor tests could provide an indication of the general applicability of the instrumentation for spilled oil detection. Nonetheless, positive results should provide sufficient basis for advancing individual types of instrumentation to the next level of development (Recommendation GM-2).

Recommendation GM-2: Evaluation and Modification of Gas Detector Sampling Intakes

Tactics and hardware associated with the use of gas detectors for subsurface oil delineation could be reviewed. For subsurface delineation, detection of upwind sources is neither necessary nor desirable. Sensor intakes should be designed to be as ground-conforming as possible and to extract vapor from as close to the ground surface (and subsurface source) as possible.

Recommendation GM-3: Detection Levels (if results of Recommendation 1 are positive)

Assuming oil can be instrumentally detected, it would be important to define a threshold concentration or degree of subsurface dispersion and weathering below which delineation is not practical. The term concentration in this context refers in part to the amount of volatile hydrocarbons released, but primarily refers to the distribution of oil accumulations.

If the bench scale tests indicate that most oil types can be detected, successful instrumentation could be confirmed using field trials. Field trials on spills of opportunity are probably appropriate, if not ideal (see Section 4.5).

4.4 Push Probes

Push Probe Technology has the capability to generate a wide variety of useful high quality quantitative data. For emergency response survey application on oiled shorelines, however, the procedure by itself may not meet the ideal objectives in several areas. Rate of sampling may exceed that of visual observations made in excavated pits and trenches. However, observations are spot samples and do not represent an improvement in capability with regard to horizontal delineation. Probe calibrations using excavations may be required. Equipment is expensive and specially trained operators are required.

Recommendation PP-1: Push probe technology is currently in use and is ready, or near ready, for shoreline field trials or demonstrations on spills of opportunity. Although the sensitivity of push probes may exceed the needs for emergency response decisions, their use may be appropriate for calibration and confirmation of other field detection and delineation procedures that do not collect vertical samples of observations, and for special uses such as NRDA.

4.5 Geophysical Techniques

Geophysical procedures have historically produced mixed results for the delineation of subsurface oil in sediment shorelines, although successful applications of these procedures have been achieved in onshore situations. Geophysical procedures are attractive in that they are very rapid, require minimal personnel and equipment, and can be set up for real-time data processing and presentation. Historically, limitations have been experienced with widely dispersed oil and sediments containing fine materials (clay) and/or salt water, and the resolution of these techniques likely limits their application to larger shoreline oiling events. Successful applications are generally associated with larger quantities of oil and continuous deposition (layering).

Recommendation GT-1: In general, equipment and operators are available for geophysical techniques, including Electromagnetics (Terrain Conductivity), Ground Penetrating Radar (GPR), and Electrical Resistivity. The procedures are ready for field trials and demonstrations on spills of opportunity, although the tactic and situation should be carefully screened to avoid failure in situations where unsatisfactory performance is predictable (light/scattered shoreline oiling).

4.6 Controlled Tests versus Spills of Opportunity Trials

Implementation of the preceding recommendations can occur at either of two levels. The first consists of controlled bench-scale or field testing in which only limited parameters are examined. Issues including detection levels, ability to detect and delineate small or scattered deposits, effects of weathering, would also benefit from further development efforts. A major objective of any further development work would be to develop promising procedures so that they are field-ready as rapidly as possible. This can be assured only through controlled and scheduled programs.

Ultimately, any promising procedure will require real-world trials or demonstrations. In many cases, the potential developing technologies outlined in this report could go directly to field trials without additional R&D. Spills of opportunity present a mechanism for such testing. Limitations associated with spills of opportunity include the unpredictable character of spills in time and space, and the ability to control the test conditions. Not all spills would be appropriate for testing or demonstration of all conditions and tactics. Testing would be limited to the oil character of the specific incident. If the character of the spill of opportunity is not appropriate for the capabilities of the procedure(s) being evaluated, the result could be a negative finding and the possible downgrading of a promising tactic from future consideration because the text was not successful. Therefore, a technical evaluation of the potential for success should take place before a test is designed.

Table 4.2 has been developed to facilitate screening of promising subsurface spill detection and delineation procedures based on spill conditions. For reference, typical survey speed and comparison with conventional tactics (pit and trench observations) are included.

Recommendation (SOO-1): Provisions for testing of high potential response tools could be incorporated in comprehensive response plans for consideration on appropriate spills of opportunity. As appropriate, procedure trials or demonstrations could be incorporated in the response action plan (with approval by the spill management team).

Table 4.3—Developing Subsurface Detection/Delineation Technologies – Field Trial Candidate Selection Matrix (for planning purposes)

OIL DISTRIBUTION	TACTIC	Survey Speed	Detection		Delineation			
					Vertical		Horizontal	
			Fresh	Weathered	Fresh	Weathered	Fresh	Weathered
Scattered (Tar Balls)	Detection Dogs	Green	Yellow	Yellow	Red	Red	Yellow	Yellow
	Gas Detect – H_2S	Green	Yellow	Red	Red	Red	Yellow	Red
	Gas Detect – Sweet	Green	Yellow	Red	Red	Red	Yellow	Red
	Geophysics – GPR	Yellow	Red	Red	Red	Red	Red	Red
	Geophysics – EM	Green	Red	Red	Red	Red	Red	Red
	Geophysics – ER	Yellow	Red	Red	Red	Red	Red	Red
	Push Probes	Red	Red	Red	Red	Red	Red	Red
Continuous/Light	Detection Dogs	Green	Yellow	Yellow	Red	Red	Yellow	Yellow
	Gas Detect/H_2S	Green	Green	Yellow	Red	Red	Green	Yellow
	Gas Detect – Sweet	Green	Green	Yellow	Red	Red	Green	Yellow
	Geophysics – GPR	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
	Geophysics – EM	Green	Yellow	Yellow	Yellow	Yellow	Green	Green
	Geophysics – ER	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
	Push Probes	Red	Yellow	Yellow	Green	Green	Yellow	Yellow
Heavy	Detection Dogs	Green	Green	Green	Red	Red	Green	Green
	Gas Detect – H_2S	Green	Green	Green	Red	Red	Green	Green
	Gas Detect – Sweet	Green	Green	Green	Red	Red	Green	Green
	Geophysics– GPR	Yellow	Green	Green	Yellow	Yellow	Green	Green
	Geophysics – EM	Green	Green	Green	Yellow	Yellow	Green	Green
	Geophysics – ER	Yellow	Green	Green	Yellow	Yellow	Green	Green
	Push Probes	Red	Yellow	Yellow	Green	Green	Yellow	Yellow
Conventional Tactics	Pits	Red	Yellow	Yellow	Green	Green	Yellow	Yellow
	Trenches	Red	Yellow	Yellow	Green	Green	Yellow	Yellow

- Green: Reasonable potential of success
- Yellow: Possible application or application with other supporting tactic
- Red: Not applicable or efficient, low potential of success

4.7 Documentation

Historically, many procedural tests have been conducted regarding subsurface oil detection on shorelines. Other than occasional anecdotal comments, few of these experiences have been documented and the results have been lost or at least difficult to access. It is important that documentation of any procedural development work be conducted in some accessible forum for future reference.

Documentation is generally not a problem with formal R&D efforts, such as those conducted by the government and the API. These efforts typically culminate in technical reports which are published in the technical literature or are accessible on websites. R&D conducted by service and instrumentation providers may, however, be considered proprietary.

Studies, trials and demonstrations conducted during spills of opportunity are commonly less formal and poorly documented, particularly if the procedure was not successful. This is unfortunate in that (1) many procedures are extremely condition-specific and may not have been implemented correctly, and (2) perceived failures are often remembered over successes. Documentation of development work and field trials conducted during spill responses are becoming more common, particularly on larger spills, but information generated is often difficult or impossible to access.

The Alternate Response Technology Tactics Evaluation System (ARTES) developed by RRTs II and III, and hosted by NOAA since 2002 provides a mechanism for evaluation and documentation of potential technologies during spill responses. Although this system was originally intended for treatment options such as treatment and recovery equipment and tactics, it was used during the Deepwater Horizon (DWH) response for evaluation of supporting technologies. Following DWH, recommendations have been made to modify this capability and perhaps add it to the ICS structure as a separate Unit (Response Technology Evaluation Unit) under the Planning Section (API 2013c). As it currently exists, ARTES includes a database which could be useful for documenting R&D efforts.

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