Overview of Fiber Optic Sensor Markets & Emerging Applications of Distributed Sensing Systems

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FiberFest 2009

Market Development

	Telecom	Sensors
1975	« R&D-Telecommunications	« R&D-Military & Industrial
1980	« Laboratory Devices	« Laboratory Devices
1985	« 1st Single Mode Long Haul Systems; Major Infrastructure	« Military Sensor R&D- gyro and acoustic
1990	« Undersea Systems	« 1st Industrial Devices
1995	« Optical Component Breakthroughs and DWDM	« 1st IFOG Applications; 1st Oil & Gas Field Trials
2000	« Optical Networks; Market Peaks in 2000 at $18B	« Broadened Gyroscope Applications; 1st Oil & Gas Systems
2005	« FTTx	« Advent of Distributed Systems

Market 2008

Optical Telecom

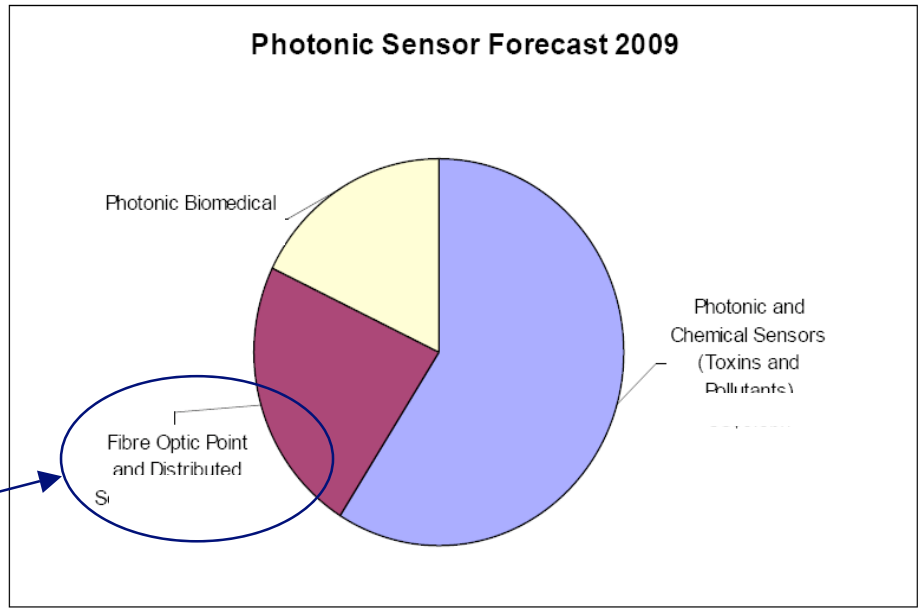
- $6,000M
- Mass-market application
- Consolidated, Hierarchical Structure
- Established standard for high bandwidth-distance transmission
- Fast adopting industry
- Slow yet steady growth in terrestrial but telecom service focus on wireless
- Cautious investment environment
- Further consolidation

FO Sensors

- $400M
- Niche markets
- Fragmented
- Foothold in niche applications
- Slow adopting industries
- Major sensing initiatives likely dominated by wireless
- Positive investment environment
- Major franchises emerging

Fiber Optic Sensor Market Snapshot

- **>$400M 2008; >$1B 2011**
  - 35% CAGR 2008-2011
- **Major Segments**
  - Military/Aerospace
  - Oil & Gas
  - Industrial
  - Security



Source: OIDA News, Volume 14, Issue 2 – September 2005.

- **Diverse Supply Base**
  - Large Cap (10)- Military/Aerospace, Oil & Gas
  - Small Cap and Private (50+)
- **Near Term Incremental Growth Segments**
  - Geophysical and Downhole Oil and Gas
  - Infrastructure Monitoring

FO Sensor Projected Market Growth

Market Segment	2008 Revenue	5-Year CAGR
Military Acoustic	$30M	30%
Military Gyro	$125M	30%
Oil and Gas: Well	$100M	35%
Oil and Gas: Seismic	$25M	70%
Industrial	$15M	15%
Security	$60M	30%
Pipeline	$10M	70%
Infrastructure	$20M	70%

Military Fiber Optic Sensors

Gyro Channel		
	Random Walk	0.07 °/rt-hr
	Bias Error	1.0 °/hr (1 σ)
	SF Error	100 ppm (1 σ)
Accelerometer Channel		
	Noise	35 ug/rt-Hz
	Bias Error	300 ug (1 σ)
	SF Error	300 ppm (1 σ)

LN200 IMU and principle performance parameters

The US Military Is The Largest and Most Sophisticated User of Sensors

Source: Northrop Grumman

Market Outlook: Military

- **FO sensing through the adoption cycle; currently serving niche but important applications**
  - IFOG Segment
    - Major wins; High volume production
    - Under evaluation for a number of new and retrofit platforms
    - Significant commercial applications
  - Acoustic Segment
    - Continued growth; hull arrays and upcoming fleet insertion of towed arrays (high sensor count)
    - Emerging commercial applications

- **New Applications**
  - Smart shipboard sensor networks
  - Chemical/ Bio-detection

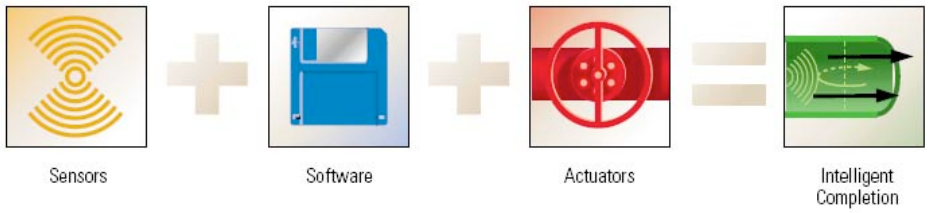
Market Outlook: Oil and Gas

- **Amid 15-Year Technology Adoption Cycle**
  - All major operators, all regions

- **Unprecedented opportunity for technology**
  - Continued focus on technology for ***brown-field*** strategies
  - High price of oil unleashes vast ***unconventional*** production
  - Increased focus on remote operations leveraging ***"smart fields"***

- **Reliability was market entry point; shift towards unique advantage of FO distributed sensing architectures**

- **Market expected to continue growth at >35% CAGR**
  - Steady growth in offshore & secondary recovery segments
  - Incremental growth:
    - Subsea sector
    - Permanent OBS

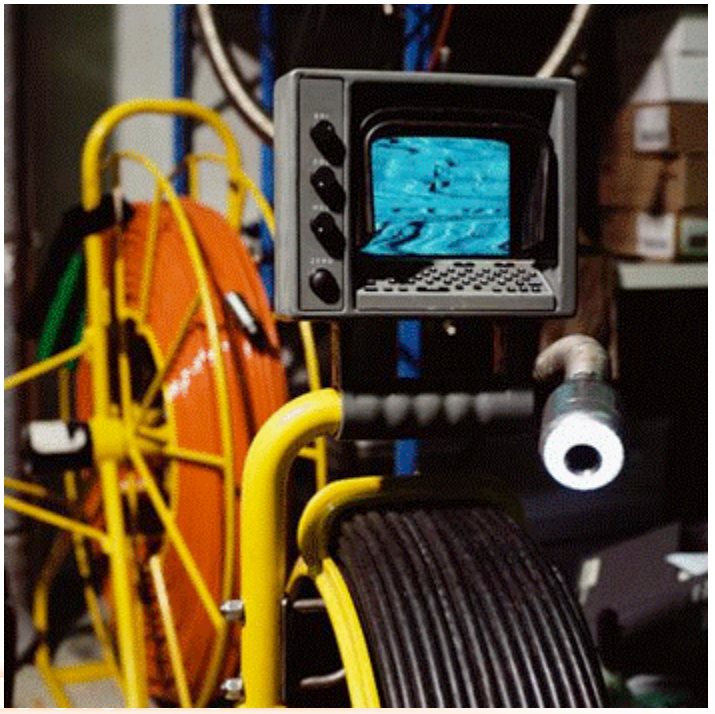


Source: Schlumberger

^ Elements of an intelligent completion.

Fiber Optic Sensors in Oil & Gas

- Launch in offshore platform sector-critical wells, demanding performance
- First commercial systems in 2000; through adoption cycle (most operators/ all regions)
- Offered by major oil field services companies: BHI, HAL, SLB, and WFT
- Distributed temp (DTS) most prevalent

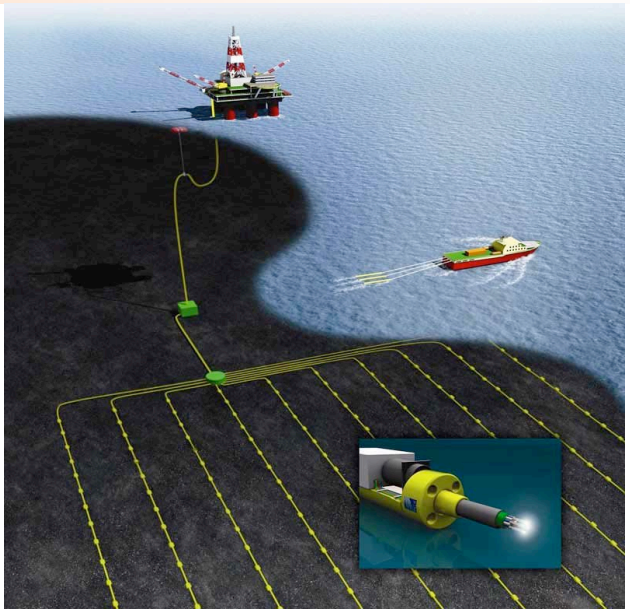


Sector	Offshore, Secondary & Tertiary Recovery
Regions	Global
Products	P/T Gauges, DTS, Flow, Seismic
Ratings	175°C, 25kpsi
Installations	>1,500 permanent
Operating Hours	>10 million

Advent of Permanent 4C OBS Systems

Major franchises formed

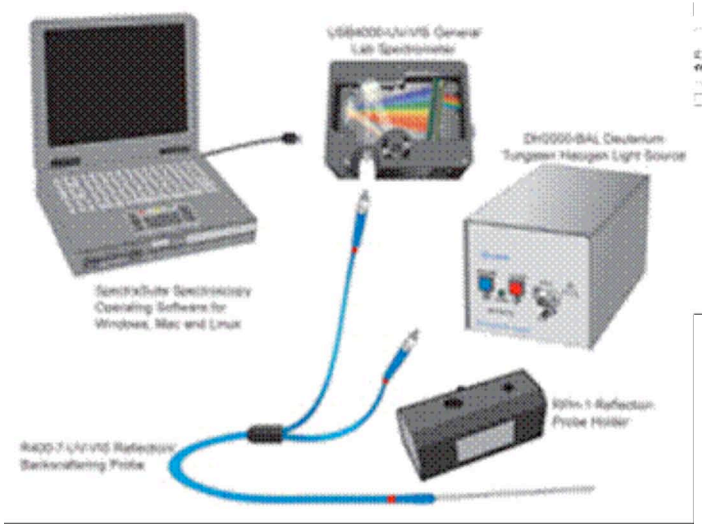
- Optical System
- Deployment
- Interpretation
- Oil Company Sponsors



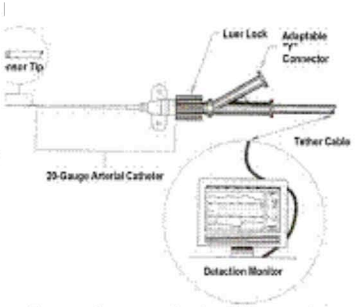
Courtesy Petroleum Geo-Services

- **Fiber Optics: reach, channel count; reliability**
- **First permanent optical OBS contract awarded to Wavefield Inseis (ConocoPhilips Ekofisk)**
- **Large integrated system; $20-50M per field to customer**

Industrial Segment: Diverse Applications

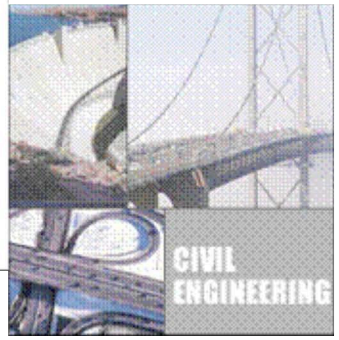


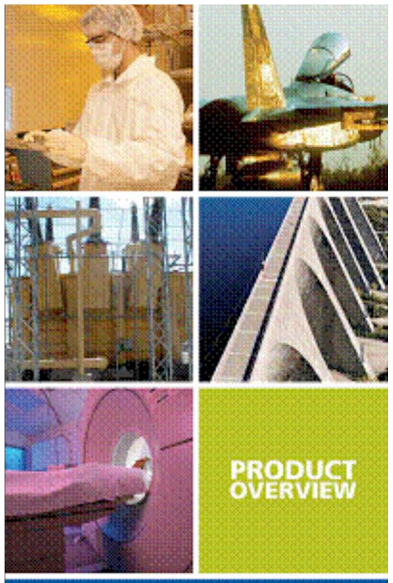
Courtesy: Ocean Optics

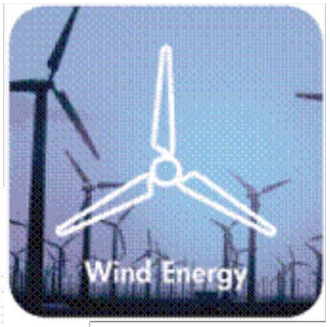


Courtesy: Intelligent Optical Systems

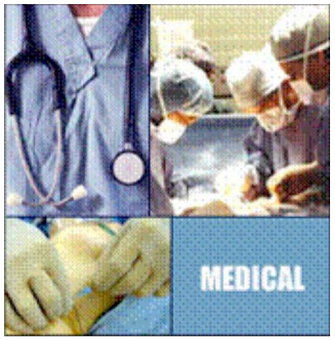
Courtesy: Opsens







Courtesy: Insensys



Courtesy: NxtPhase

Courtesy: FOS&S

Courtesy: FISO

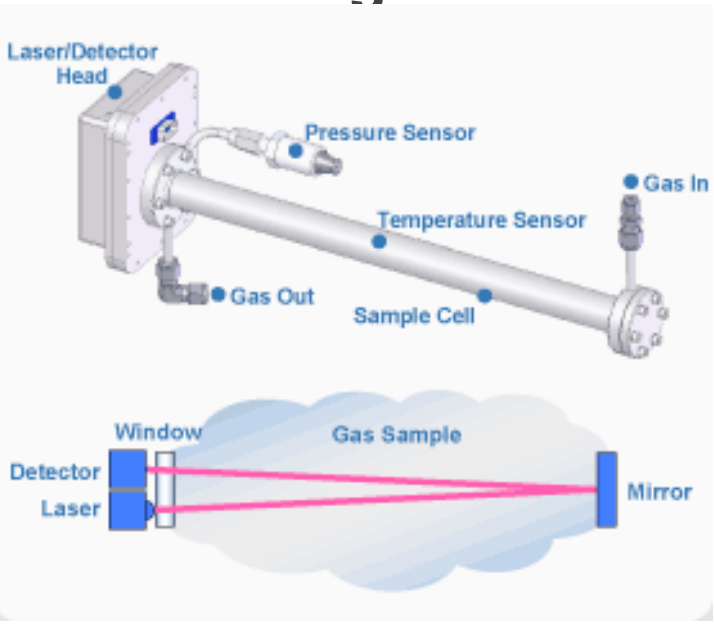
Market Outlook: Industrial

- **Diverse markets and applications**
- **Photonic spectroscopic NIR monitoring and gas detection a robust area but not included in forecast**
- **FO sensing products currently serve applications that leverage attributes of FO (form factor, EMI/RFI, etc.)**
  - Medical
    - Temperature
    - Pressure (MRI; Intra-aortic and Intracraneal Pressure)
  - Industrial
    - Manufacturing process control- all measurands (temp/pressure/n_r/strain/displacement/other)

Photonic Spectroscopic Sensors

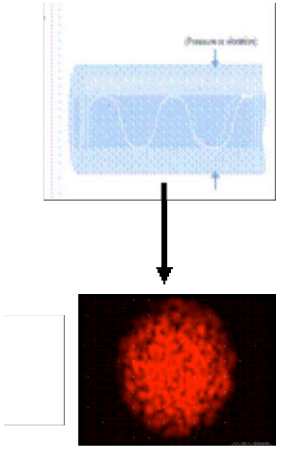
- **Laser-Based NIR moisture monitoring of pipelines; adjacent trace gas monitoring (H_2S)**
- **Emerging Mid-IR monitoring of hydrocarbon lines**
  - practical, field suitable sources and detectors
- **Significant cost savings over conventional sampling and chromatography methods**
- **Readily Networked, in-situ, real-time monitoring**

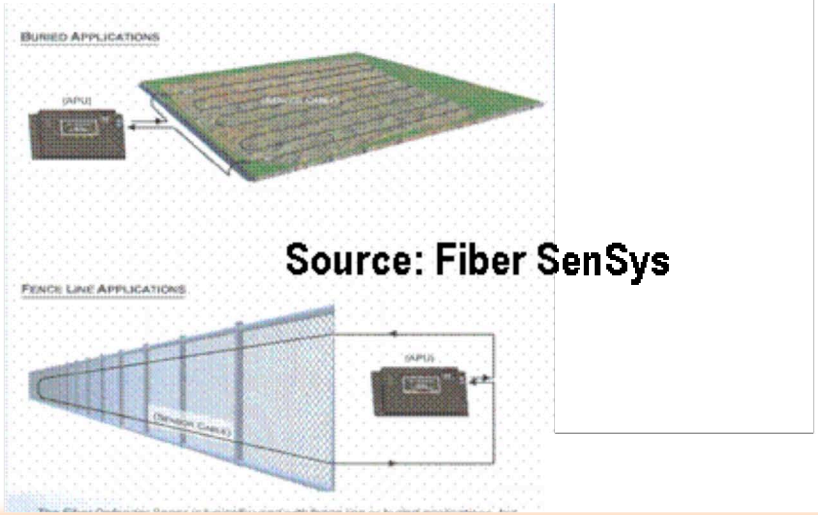
SpectraSensors



Market Outlook: Security

- **100s first generation systems deployed and operating**
  - Perimeter intrusion detection
- **High growth potential in major infrastructure security initiatives**
  - Pipeline and critical asset security
  - Cargo containers
  - Wide area surveillance
  - Chemical/bio-agent detection
- **Market growth subject to uncertainty of funding**
- **Highly competitive technologies (wireless)**



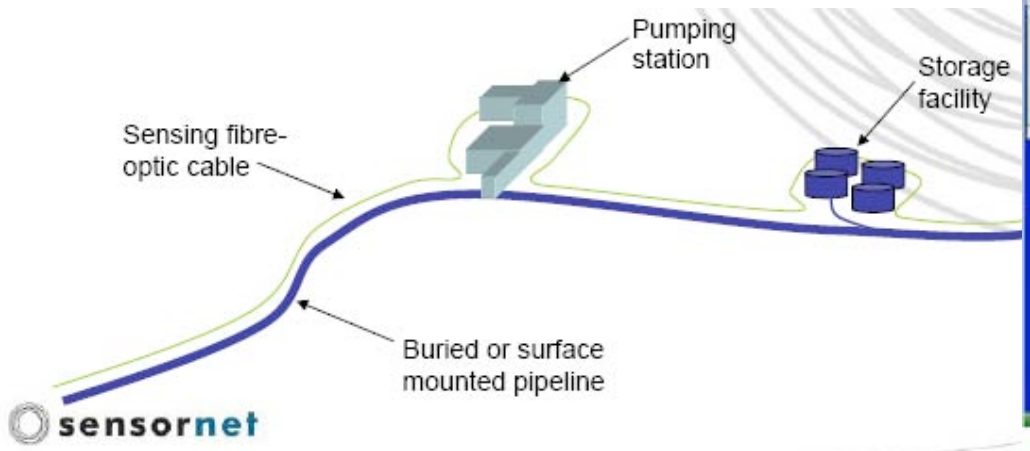


Source: Fiber SenSys

FiberPatrol fence sensor with integrated camera drop.

Security

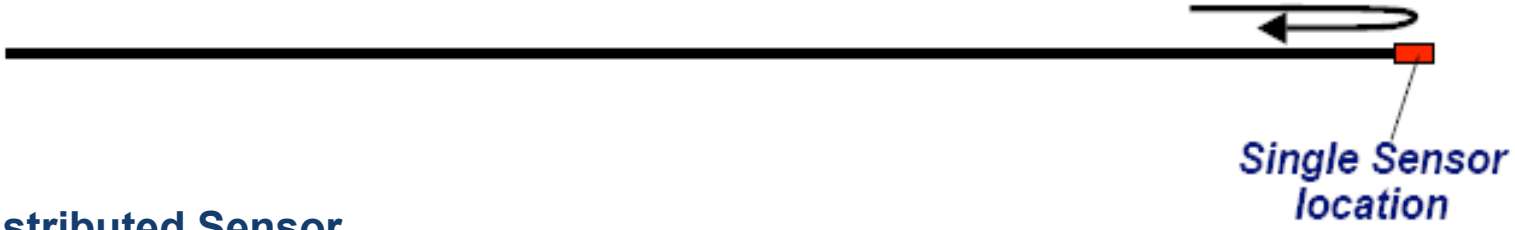
- Perimeter monitoring to detect intrusion
  - Part of “deter, detect, delay, deny” asset security approach
  - Sensors linked to network alarm and video analytics
- Challenge: false alarms
- Distributed fiber optic solutions well-suited; 1st generation in wide deployment:
  - Fiber mode intensity (“speckle-pattern”)
  - OTDR systems in wide deployment
- FO acoustic sensing through trials and early deployment; major advantages
  - Sensitivity and distributed architcture
  - Intelligence; adaptive via acquisition of “library” of intrusion signatures



Command & control interface providing situational awareness at remote facility

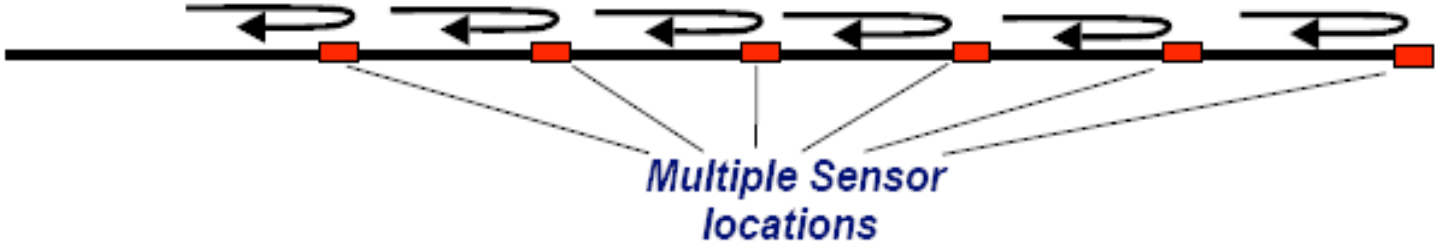
Basic Architectures

Point Sensor



Fully Distributed Sensor

Distributed Point Sensor



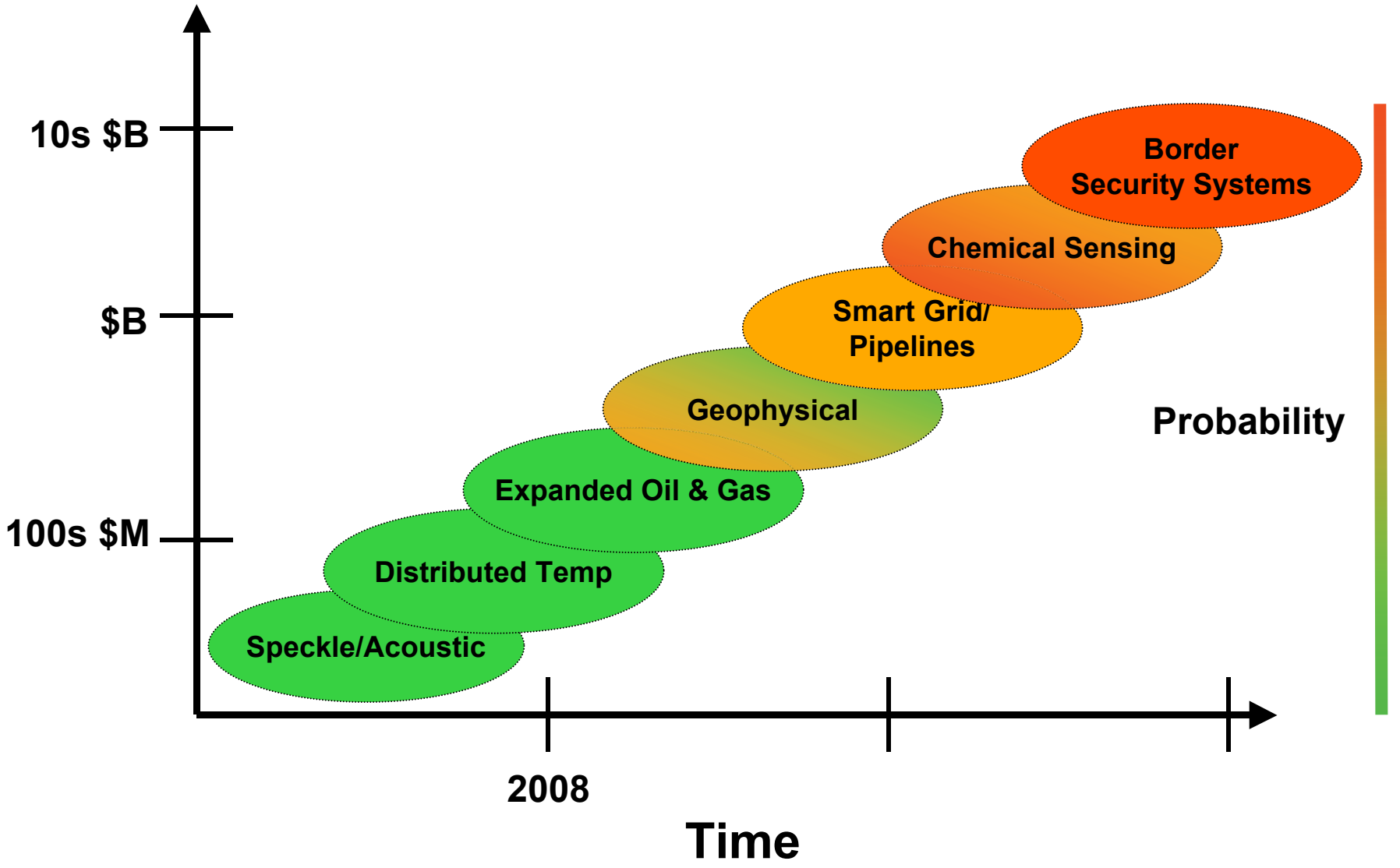
Fiber optics: bandwidth/distance capability to support multiple sensors/channels on single fiber

FO Sensor Market Drivers

- **Initial penetration in applications that afford high price per sensing point that leverage inherent advantage of FO:**
  - Form (size/weight/relative performance) – ***Gyro, Acoustic***
  - High Temperature/Reliability- ***Oil & Gas***
  - EMI/Dielectric- ***Medical MRI***

- **Distributed sensing poised to dominate FO sensor applications going forward**
  - Realize advantages of fully distributed sensing architecture
    - ***Competitive price per sensing point***
    - ***Data interpretation possibilities by tracking events over large number of points***

Distributed Sensors Will Drive Applications



Example: Oil and Gas DTS

Source: Sensa

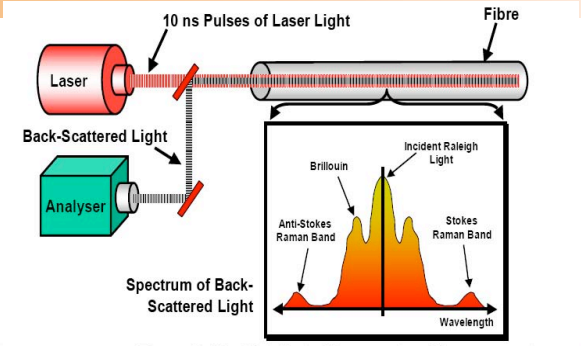
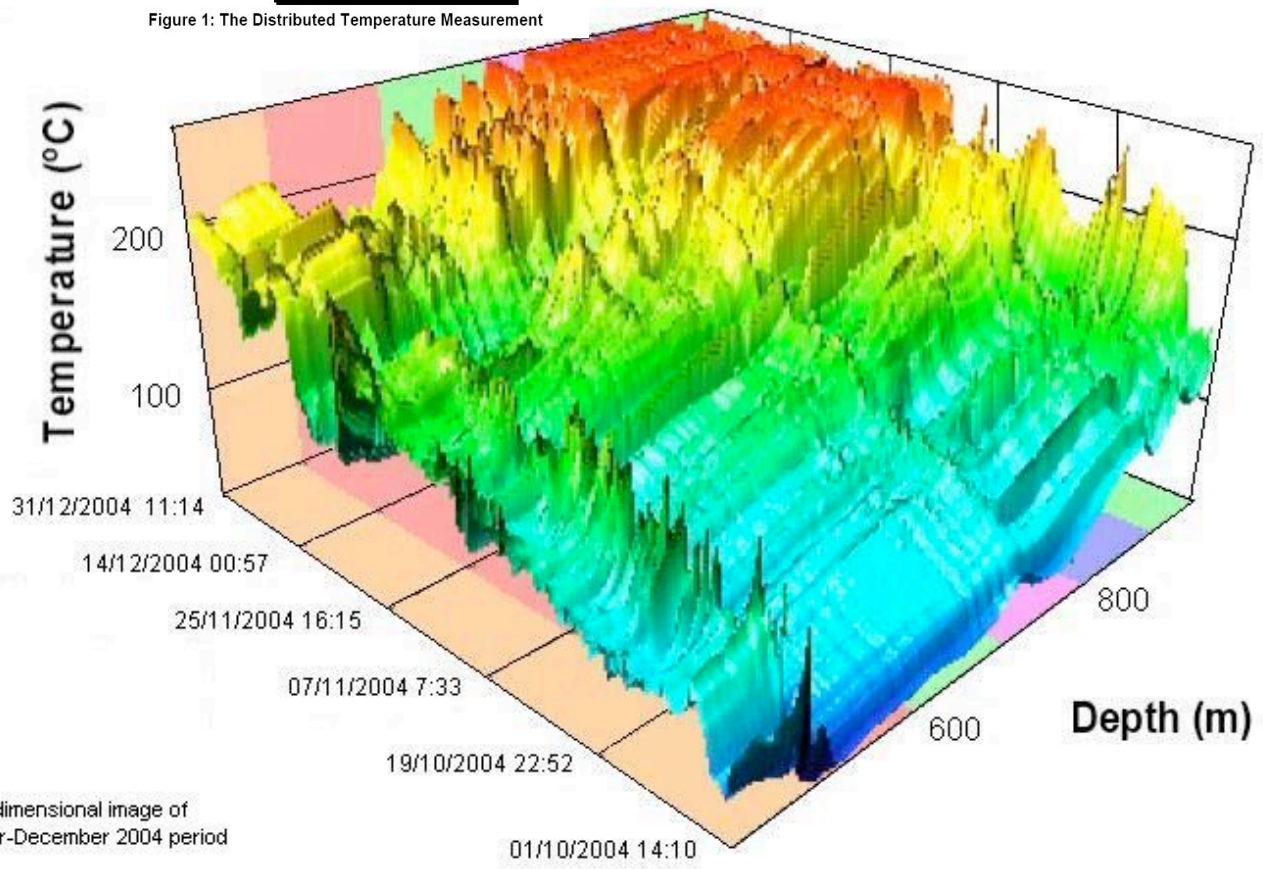


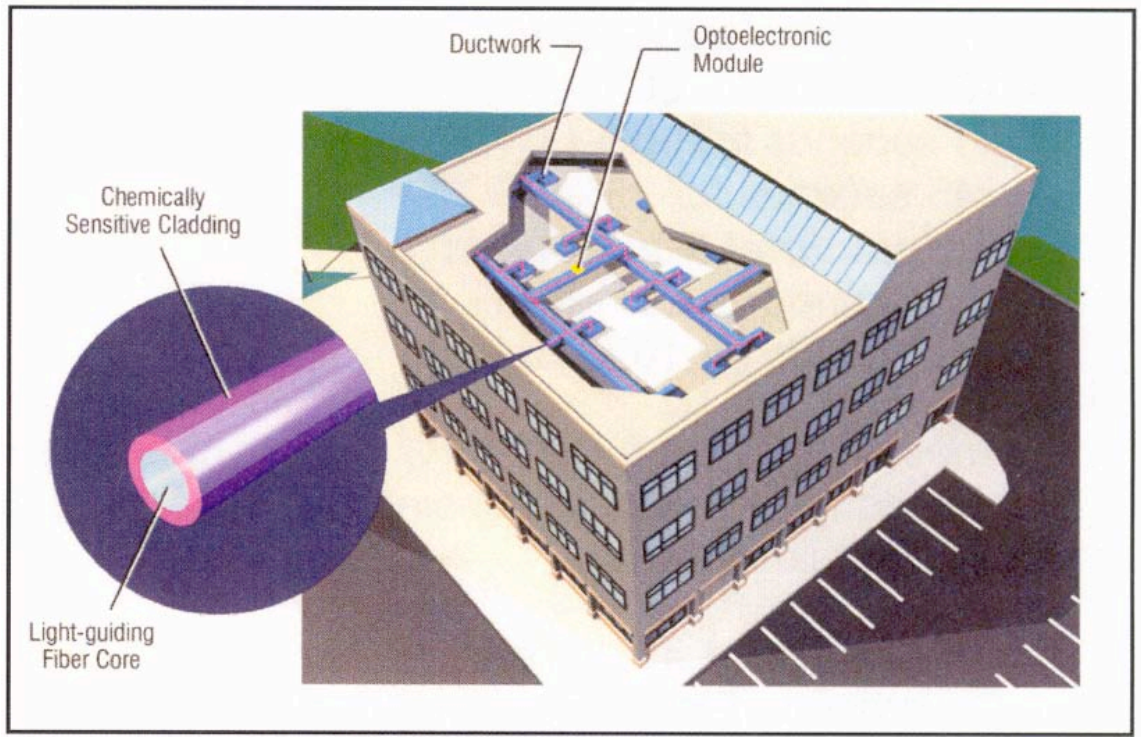
Figure 1: The Distributed Temperature Measurement

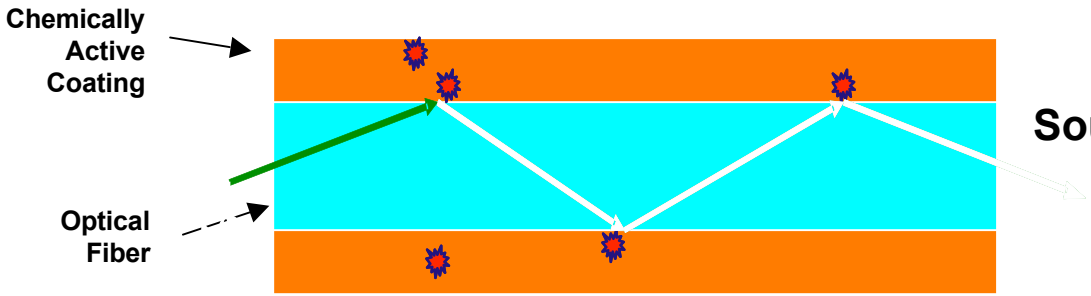


Three-dimensional image of October-December 2004 period

Reference: SPE 102159 P. Krawchuk

Example: Distributed Chemical Sensor

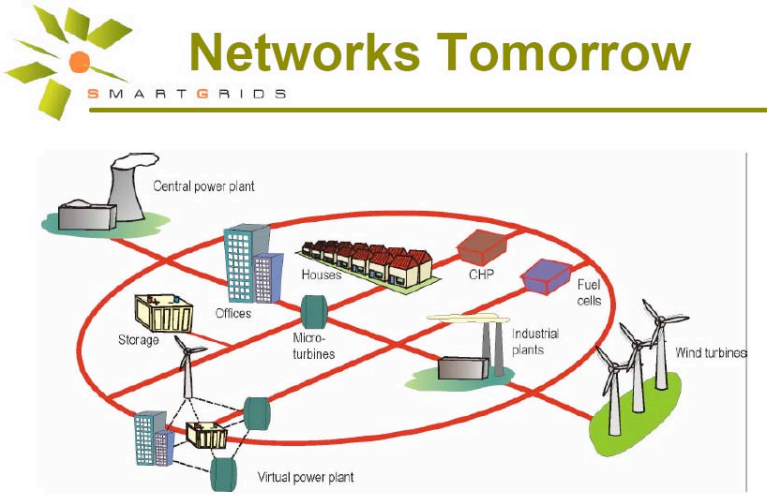




Source: Intelligent Optical Systems

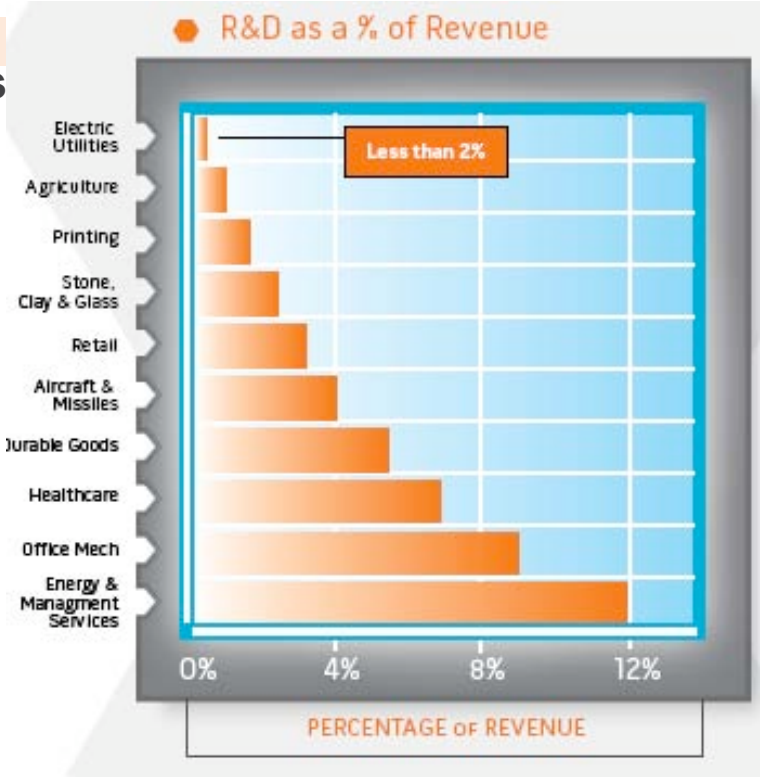
Smart Grid

- **Energy Security and Independence Act of 2007 (Title 13)**
  - $100M pa funding 2008-2012
  - Other reimbursements and incentives
- **Promoted by EU Smart Grid European Technology Platform; significant activity in Asia**
- **Major Public/Private Partnerships**
  - Gridwise Alliance
  - Demand Response and Smart Grid Coalition
  - EPRI/Intelligrid
  - NIST Gridwise Arch. Council
  - Galvin Electricity Initiative



NA Electric Power Infrastructure

- 3,000 utilities, 2000 independent power producers
- $275B revenue; 100% >Telecom, 30% >Auto
- ~$1T in assets; 70% plants, 30% grid
- 700,000 miles HV transmission lines, 5MM miles MV distribution lines, 22,000 substations
- ~$100B annual infrastructure investment, North America 25%
- Upgrade of infrastructure has not kept pace with growth
- Industry slow at adopting new technology
- Major grid vendors however are technology leaders: ABB, GE, Siemens



The industry is planning to invest [in transmission] at levels not seen in nearly 30 years.
Edison Electric Institute, May 2005

Running today's digital society through yesterday's grid is like running the Internet through an old telephone switchboard.
Energy Future Coalition

The network and the system need to be modernized and brought into the digital age. The advantages and opportunities for huge technological and economic gains are enormous.
Morgan Stanley Energy Insights, September 2005

Uncertainty about the terms under which transmission investment may be recovered stands as a major barrier to new investment.
Consumer Energy Council of America January 2005

Source: Global Environment Fund

DOE Smart Grid Technology Initiatives

ADVANCEMENTS ALSO IN DEVELOPMENT...

Zero-net energy commercial buildings:

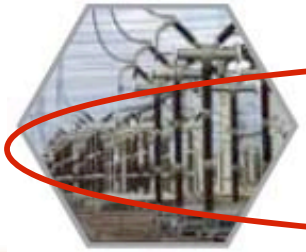
Whether measured by cost, energy, or carbon emissions, structures equipped with Smart Grid technologies capable of balancing energy generation and energy conservation.

Superconducting power cables:

Capable of reducing line losses and carrying 3-5 times more power in a smaller right of way than traditional copper-based cable.

Energy storage:

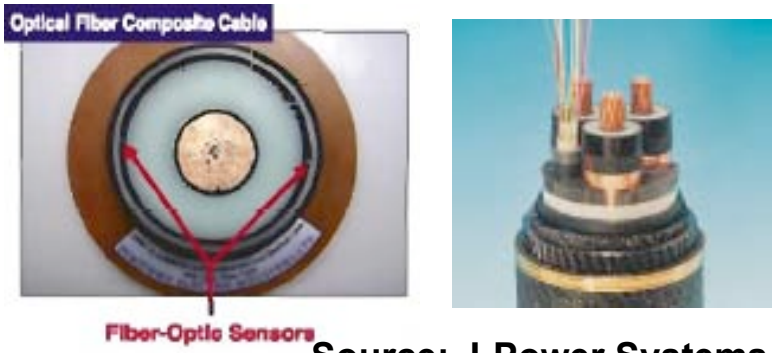
While electricity cannot be economically stored, energy can be – with the application of Smart Grid technologies. Thermal storage, sometimes called hybrid air conditioning, holds promising potential for positively affecting peak load today. Also of note is the near-term potential of lithium-ion batteries for PHEV applications.



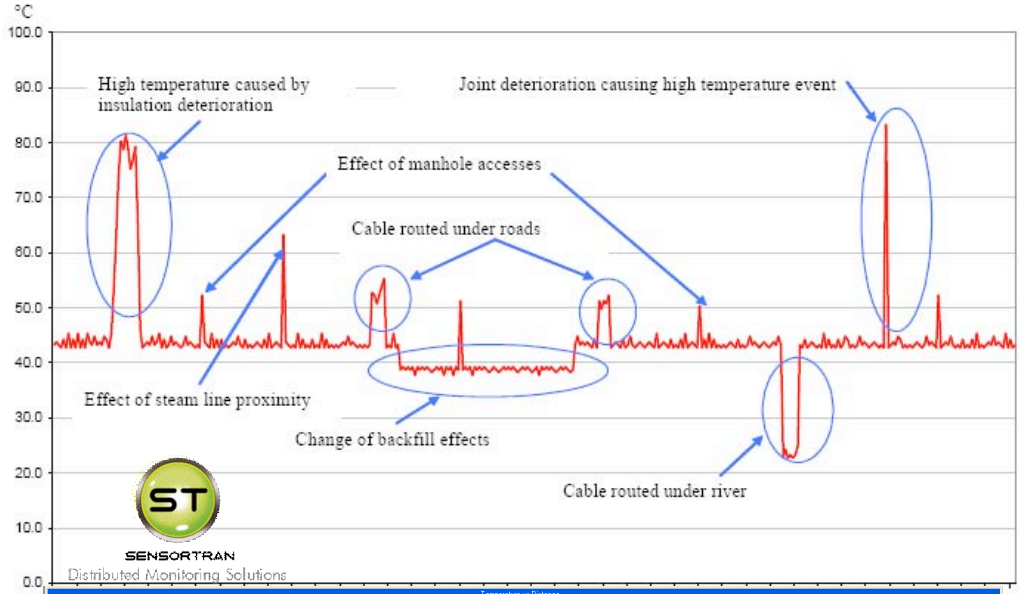
Advanced sensors:

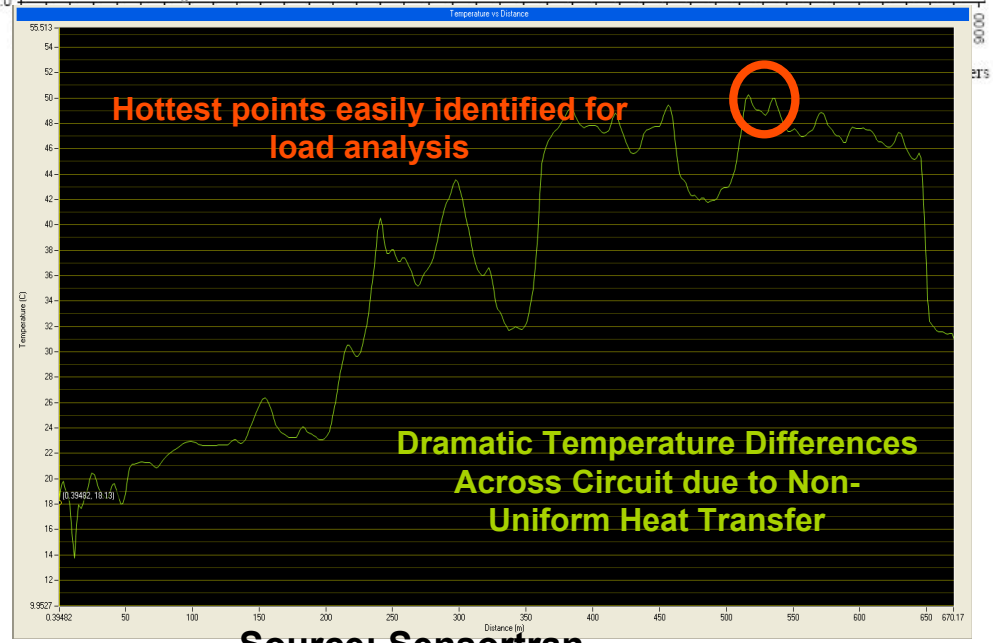
Monitoring and reporting line conditions in real time, advanced sensors enable more power to flow over existing lines.

Example DTS Power Cable Monitoring



Source: J-Power Systems

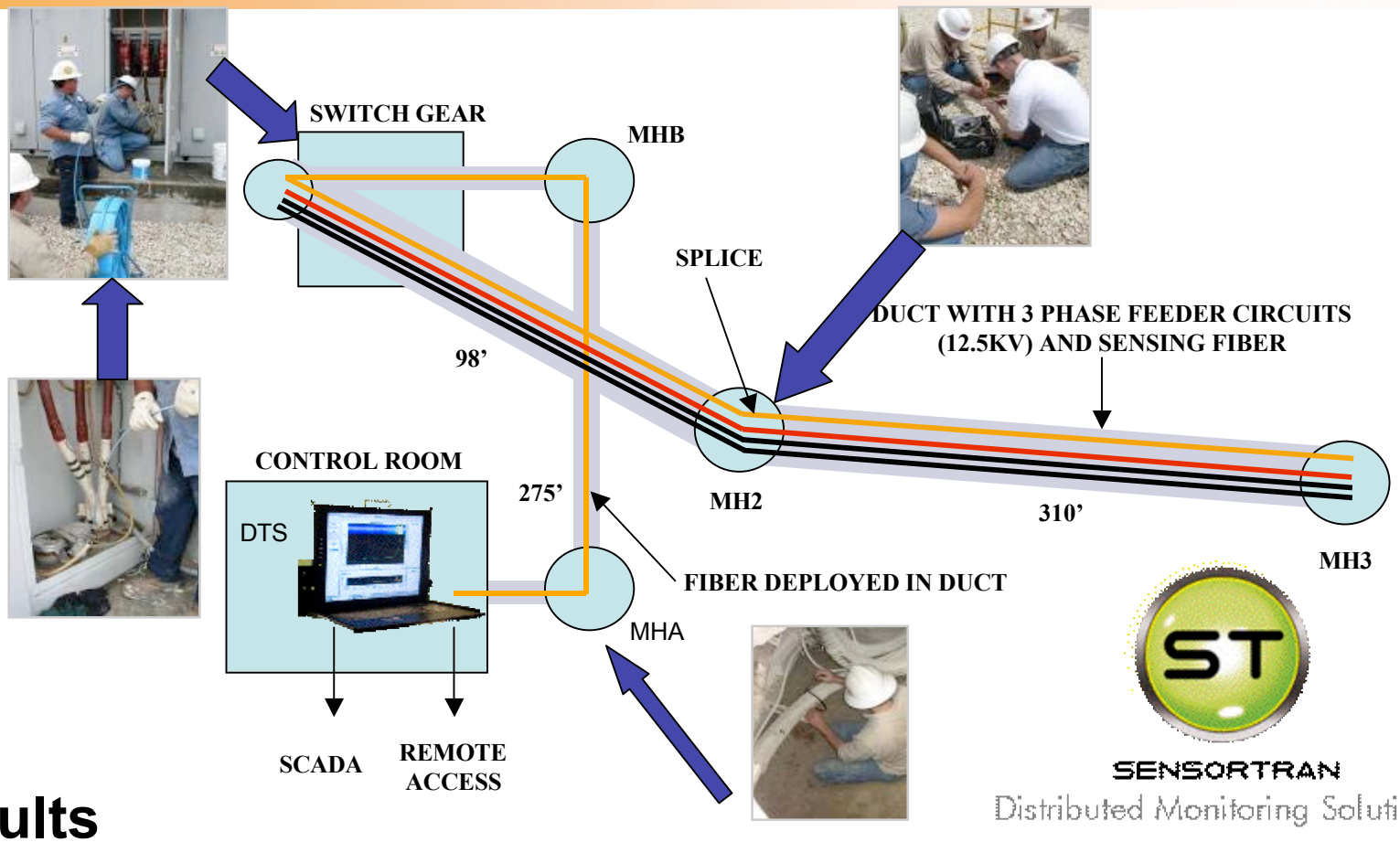




Source: Sensortran

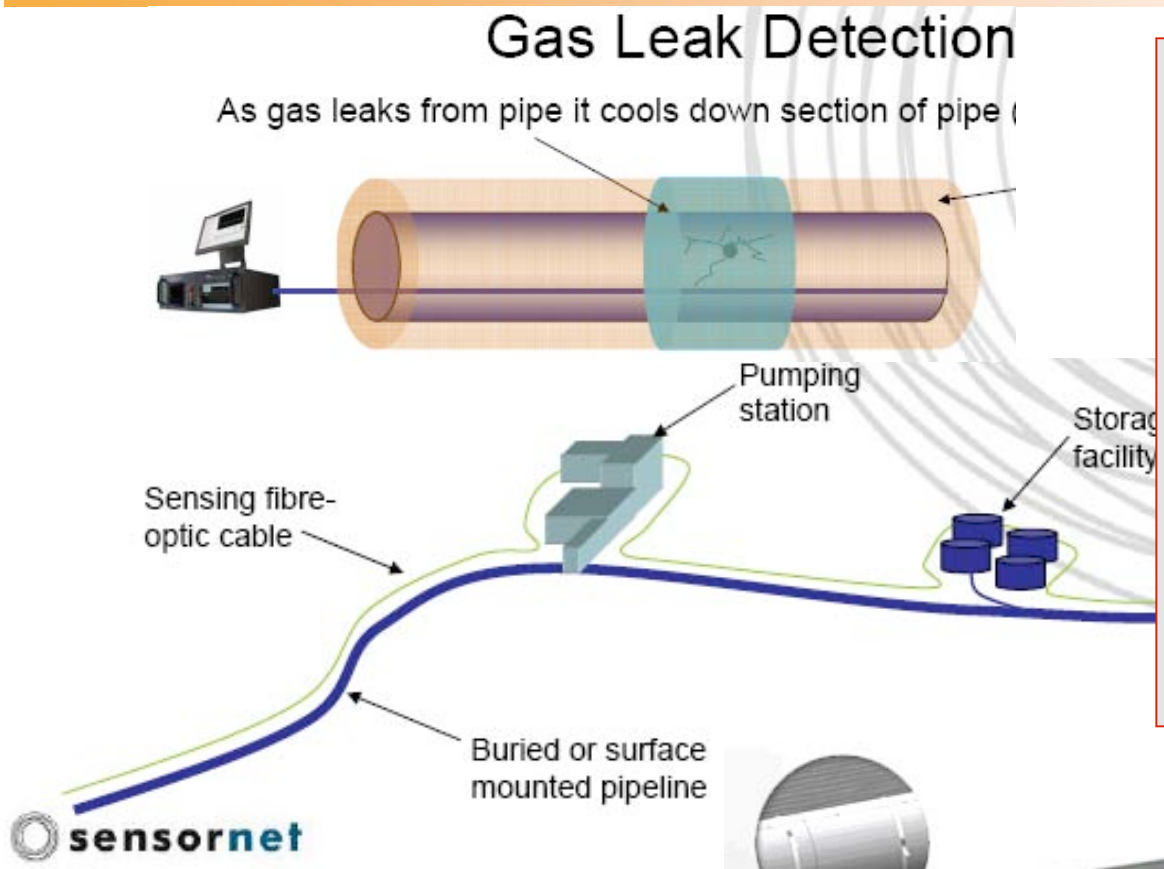
- Increased Capacity
- Improve Circuit Utilization to Thermal Environment
- Condition of Assets
- Hot Spot Detection
- Load Analysis
- Sag in Overhead Cables

Trial: Improve Utilization of Existing Circuitry



- **Results**
  - Each circuit's Amperage changed to 600A (20% increase)
  - Demonstrate capability of permanent DTS monitoring to dynamically optimize cable loading without risk to circuit

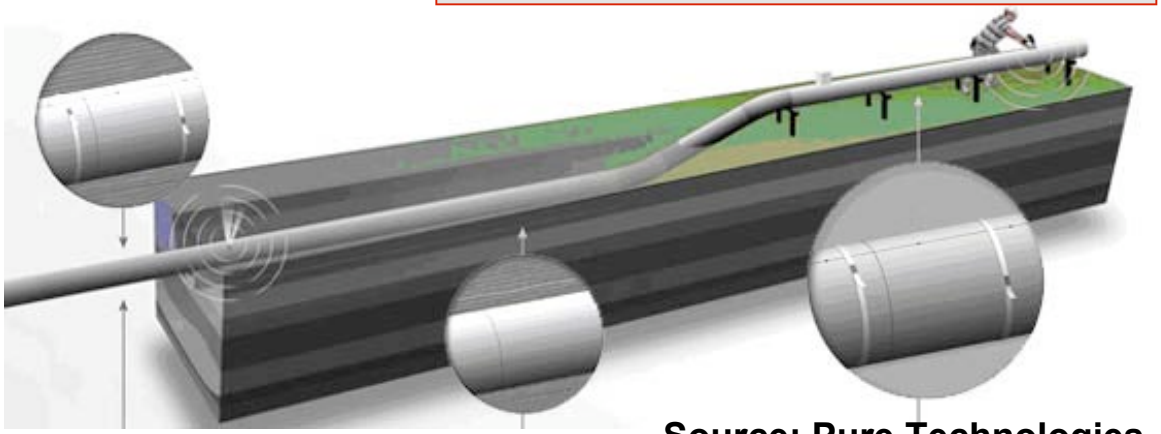
Pipeline Monitoring: Integrity and Security



Integrity/Holistic
- Leak detection
- Wall Thinning

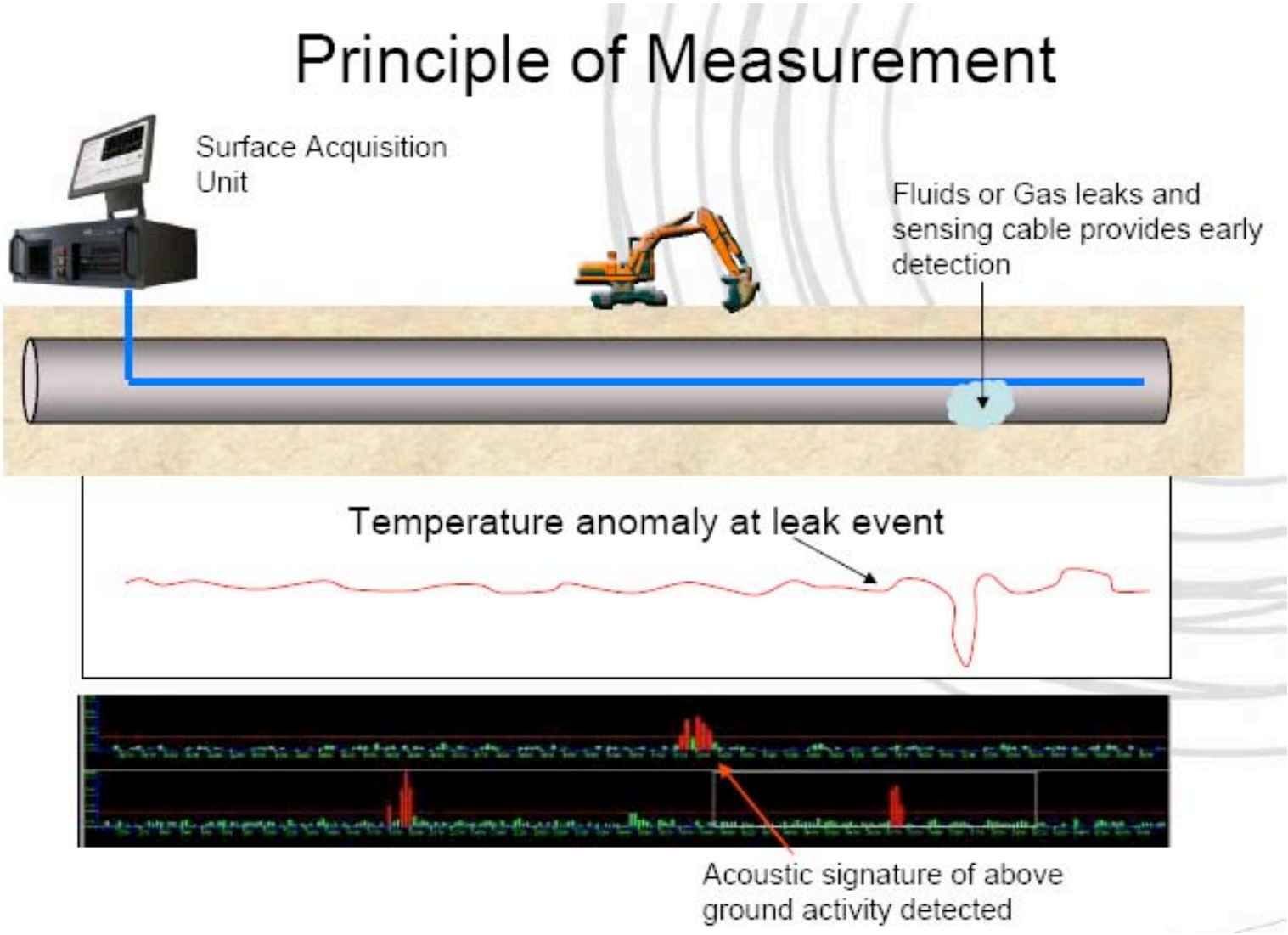
Security
- Perimeter Monitoring
- Intrusion Detection

Gas/Chemical Sensing
- Moisture/H_2S



Source: Pure Technologies

Thermal/Acoustic on Same Fiber

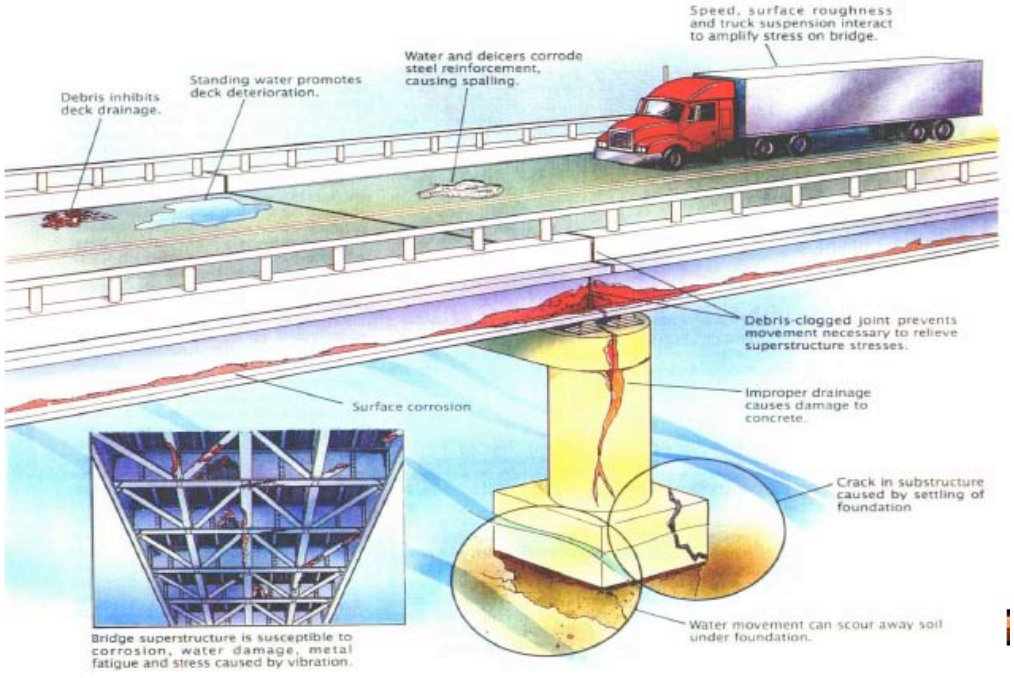


Source: Sensornet

Infrastructure Monitoring

- **2006 FHA study: 25% bridges structurally deficient or obsolete**
- **Major initiative**
  - 600,000 bridges
  - 1 Million miles water main
  - 4M miles highway
- **NIST TIP award**
  - DST Inc. and partners
  - $8.5M
  - Integrated Brillouin and Coherent OTDR

Driving Factors for On-line Monitoring:
Decaying Civil Infrastructure



Fiber Optic Sensor Commercialization

- **Must be compelling relative to alternate technology**
  - ➢ Cost, then performance
- **Must be systems-level offering**
  - ✓ Data management and interpretation
  - ✓ Deployment and tech support
  - ✓ Customer training
- **Must have established channel to the end-user**

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