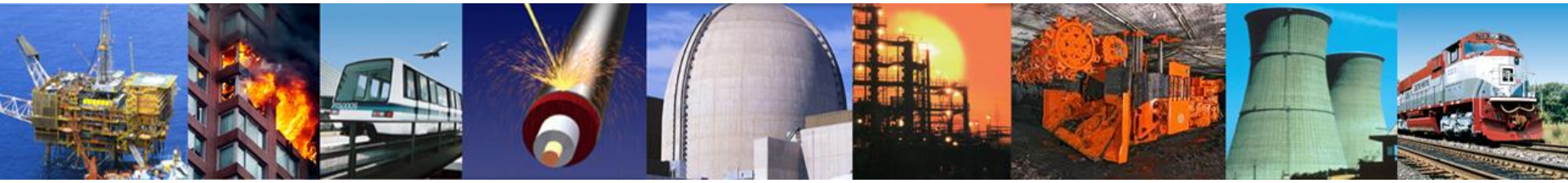
Marmon Engineered Wire & Cable LLC
A Berkshire Hathaway Company

Temperature Sensing Challenges in the Oil & Gas Industry

Graeme Young – Marmon EWC
18 April 2018



Agenda

Marmon Engineered Wire & Cable LLC
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- Marmon Group and Global Markets
- Oil & Gas Market Segments
  - Upstream Applications
  - Midstream Applications
  - Downstream Applications
- Distributed Fiber Optic Sensing - Global Installations (source: FOSA)
- Temperature Sensor – Market Size
- Summary

The Marmon Group at a Glance

Marmon Engineered Wire & Cable LLC
A Berkshire Hathaway Company

- Marmon Holdings, Inc., part of Berkshire Hathaway, Inc., is a global, diversified industrial organization employing 20,000 people worldwide
- Marmon comprises four autonomous companies consisting of 16 diverse, stand-alone business sectors and 185 independent manufacturing and service businesses.

Marmon Engineered Components Company

- Engineered Wire & Cable (EWC)
- Distribution Services
- Tubing, Fittings & Wire Products
- Industrial Products
- Engineered Products & Services

Marmon Energy Services Company

- Rail Products & Services
- Intermodal Containers
- Crane Services

Marmon Food, Beverage & Water Tech. Company

- Food Service Technologies
- Beverage Technologies
- Water Technologies

Marmon Retail & Highway Tech. Company

- Retail Science
- Retail Store Equipment
- Retail Products
- Highway Components
- Trailer & Truck Products and Services

Marmon Engineered Wire & Cable - Member Companies

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- Marmon (EWC) is a unique group of 15 major cable and sensing Companies; design and manufacture of cables and sensors for harsh environments
- North America, UK (CCPI Europe) and India (Radiant-RSCC Joint Venture) Marmon EWC : 1600 employees

Power/Utility	Applied Sensor Solutions	Military/ Aerospace	Energy/Industrial	Supply/Support
Hendrix	COMTRAN CABLE ENGINEERED QUALITY	MARMON Aerospace & Defense Mission Critical Connectivity Systems	RSCC World Class Engineered Cable	GENDON POLYMER SERVICES INC
kerite	TEW&C	KITCO fiber optics	Dekoron Wire & Cable LLC INDUSTRIAL CABLE SOLUTIONS	OWLWIRE
	DEKORON Unitherm Tubing Bundle Experts Since 1962	Harbour INDUSTRIES High Performance Wire & Cable	CABLE USA	
	CCPI Europe Limited		RADIANT-RSCC Specialty Cable Private Limited	

Marmon Group – Global Markets

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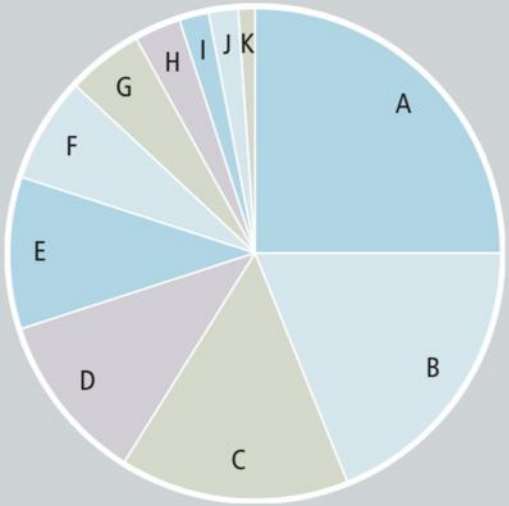
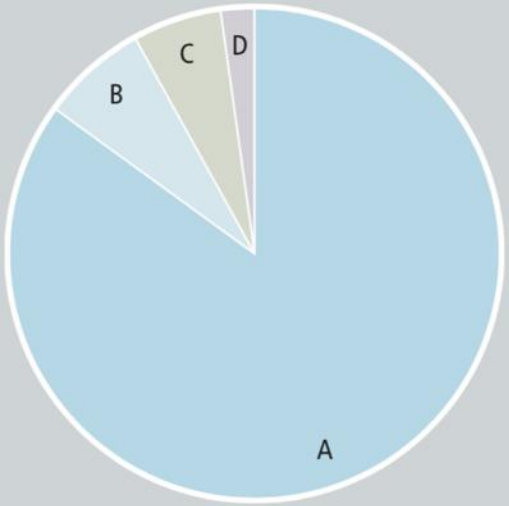


End Markets (% of 2016 revenues)

- **A** Energy, Mining & Petrochemical **27%**
- **B** Construction & HVAC **18%**
- **C** Retail Stores & Restaurants **16%**
- **D** Industrial **10%**
- **E** Heavy-Duty Vehicles (OEM & Aftermarket) **10%**
- **F** Consumer **6%**
- **G** Transportation Providers **5%**
- **H** Food & Agriculture **4%**
- **I** Aerospace & Military **2%**
- **J** Construction & Agricultural Equipment **1%**
- **K** Other **1%**



Geographic Markets (% of 2016 revenues)

- **A** North America **85%**
- **B** Europe **7%**
- **C** Pacific Rim **6%**
- **D** Other **2%**

Source: Marmon Holdings Brochure 2016

Oil and Gas Industry - Market Segments

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Upstream

- Geological Surveys
- Exploration & Production (E&P)
- “Wellbore”

Midstream

- Transportation: e.g. Pipeline, rail, tanker, truck
- LNG Terminals
- Storage

Downstream

- Refining
- Petrochemical
- Marketing and Distribution

Upstream Application – In-Well Temperature Monitoring SAGD Wells

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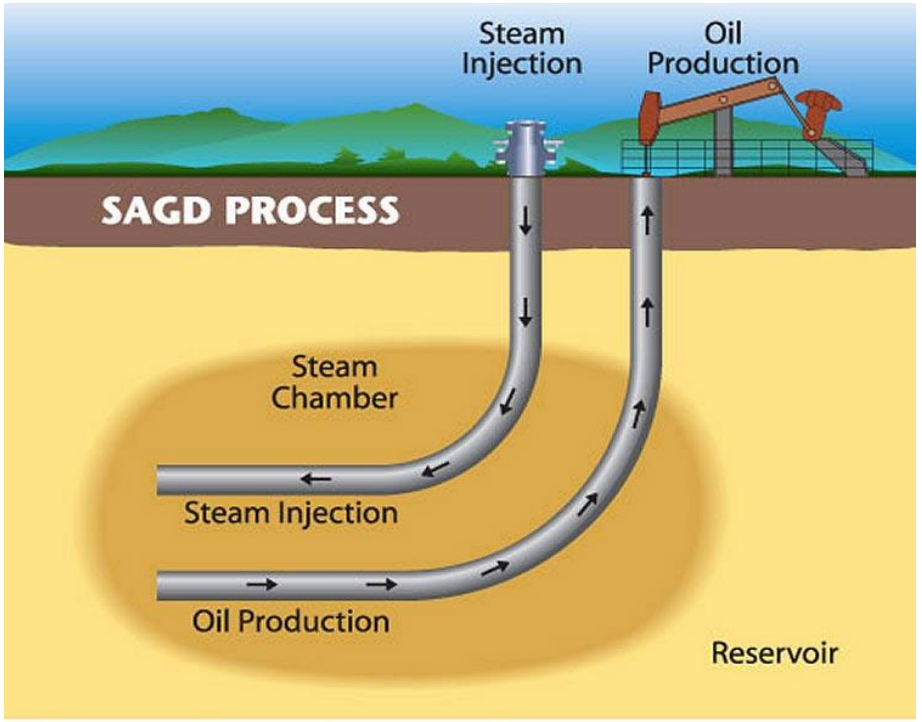
Application Outline

Steam Assisted Gravity Drainage
Bitumen / Heavy Crude
Thermal Enhanced Oil recovery method
Downhole temperatures 235 – 350^{0}C
Reduce viscosity of Bitumen, pump to surface
Continuously monitor thermal profile of both Injection & Production well

Key measurable SOR (steam-oil ratio)

- SOR typically < 2.5
- 2.5 bbls steam to produce 1 bbl oil



Source: Canadian Centre for Energy Information

Challenges

Permanently installed, long duration (years)

- Non-retrievable, no access to replace temperature sensor

Hydrocarbon / Pressure environment; pressure barriers, temperature cycling

Upstream Application - In-Well Temperature Monitoring SAGD Wells

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Current Temperature measurement methods

Thermocouples (Bundles) – best long term durability

Distributed Fiber Optic Sensing (DTS)

- At limit of Operating Temperatures (300^0C)
- Limited life span, hydrogen darkening

*Enhanced / New Temperature measurement methods – **EMPRESS Projects***

- Low Drift, Dual Wall Thermocouples – improved performance for long term installation
- Slimline integrated, self-validating thermocouples, potential development at 300 – 600^0C range (EMPRESS 1)
  - Improved temperature measurement over long durations (years)

Traceable Fiber Optic thermometry (ITS-90)

- Standardised calibration techniques for existing and new fiber optic sensors
- Traceable temperature measurements up to 660^0C (improved coatings for FO)
- Phosphors, Bragg Gratings & Distributed Temperature Sensing

(Note : IEC 61757-2-2 Ed. 1.en:2016. “defines detailed specifications for distributed temperature measurement by a fiber optic sensor”)

Energy related In-Well Temperature Monitoring - Geothermal Wells (Boreholes)

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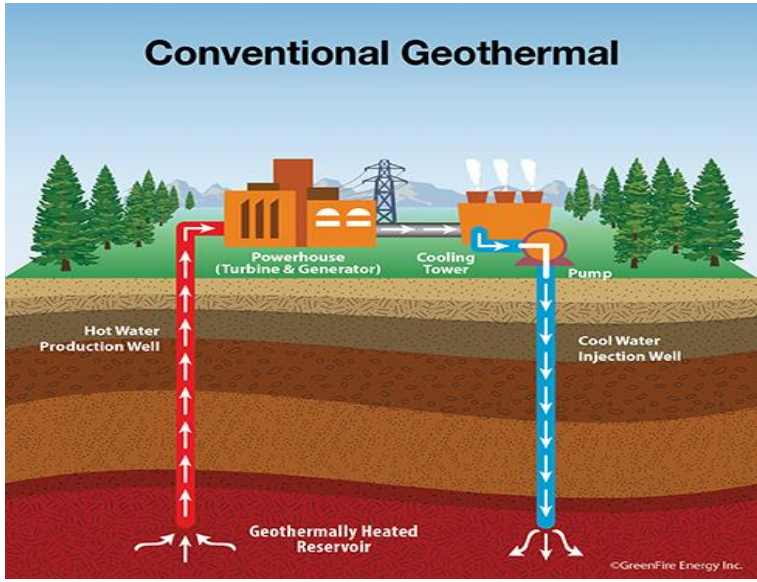
Application Outline

- Renewable – Geothermal Electricity Generation
- California, Philippines, Indonesia, Iceland (tectonic plate boundaries); 20+ Countries
- About 2800 wells, concentrated into 'fields'
- Current Technique used to monitor downhole temperature;
  - Thermocouples (downhole temperatures typically above fiber optic capability)



Challenges

Permanently installed, long duration (many years)

- Non-retrievable, no access to replace temperature sensor, up to 3 miles deep

Temperature range 300^0C up to 600^0C; vibration

New / Enhanced Temperature Measurement techniques

- Low drift / slim-line self-validating thermocouples
- Traceable Fiber Optic Thermometry (ITS-90), higher temperature up to 660^0C

Midstream Application – Pipeline Temperature Monitoring

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Application Outline (Leak detection; temperature)

- Very efficient transport mode for hydrocarbons
- Leaks can be caused by ground movement, corrosion, material failure, 3rd Party intervention and also improper operating procedures
- Continuous monitoring required for pipeline integrity
- Many different monitoring technologies;
  corrosion, pressure wave analysis etc and
  temperature measurement along pipeline

Challenges

- Permanently installed, long distance
- Retrofit monitoring difficult and expensive
- Underground and over ground pipelines
- Expansion, contraction, vibration during operation
- Ground movement over time
- Rapid indication of leak (small temperature change)
- Pipeline Leak Detection legislation
  - API RP 1175

Midstream Application – Pipeline Temperature Monitoring

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Current Temperature Measurement Methods

- DTS – Distributed Temperature Sensing in conjunction with DAS (acoustic) and DSS (strain)
- In excess of 200 pipelines monitored using DTS
- Leaks –catastrophic to environment and reputations (HSE and shutdown costs)
  - Linear Asset Monitoring
    - Gas pipeline leak; Joule-Thomson effect
    - Oil pipeline leak; temperature changes (a few ^{0}C for oil) external to the pipe

Enhanced / New Temperature Measurement Methods

Traceable Fiber Optic Thermometry (distributed Temperature sensing) ITS-90

Gas Pipeline monitoring (J-T effect)

Temperature measurement is at the core of pipeline monitoring however additional techniques are required for Oil Pipelines – Entire Surface monitoring, Electromagnetic / Wave propagation etc for Pipeline leak detection

Midstream Application – LNG Pipeline and LNG Plant Temperature Monitoring

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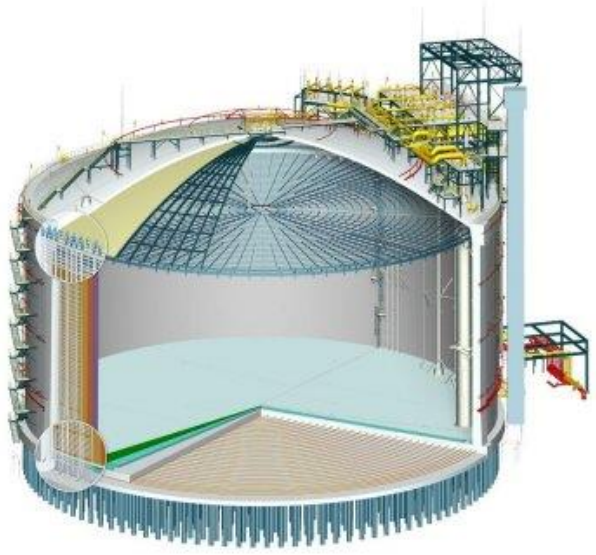
Application Outline

Transporting and storing liquefied natural gas (LNG) as a liquid **(-162^{0}C) 111 kelvin**

- Temperature monitoring of LNG Plant, LNG Pipelines, LNG Storage tanks
- Distributed Fiber Optic Temperature Sensing for LNG Pipeline monitoring ; LNG Tank monitoring helically wrapped around inner tank (annulus)
- Fiber acts as a passive sensor; no electronics or power; sensing immune to EMI

Challenges

- Primary threat to safe LNG operation is tank / pipeline leakage
- Continuous real-time monitoring of entire LNG surface area (tanks / pipelines)
- Rapid indication of small temperature change required



Midstream Application – LNG Pipeline and LNG Plant Temperature Monitoring

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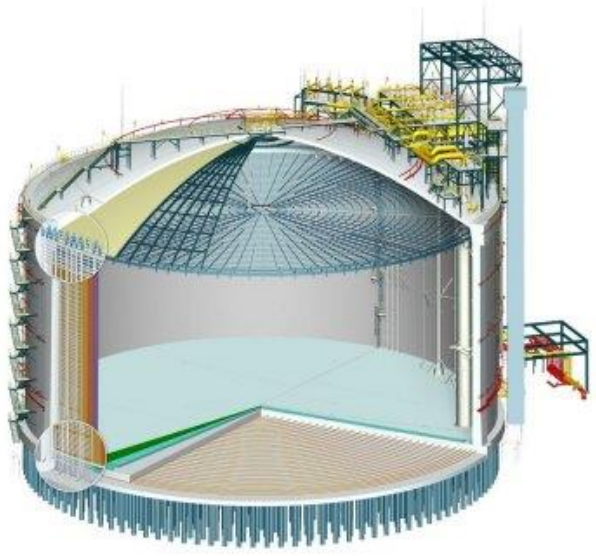
Current temperature measurement methods

- Distributed Temperature Sensing (DTS) widely used in LNG Plants at cryogenic conditions (**-162^{0}C**)
- Fiber Optic sensing safe operation in explosive environments
- Leaks catastrophic - people, environment and reputations
- Single point temperature measurements also used in LNG Plants

Enhanced / new temperature measurement methods

- DTS temperature measurement, (Raman, Rayleigh and Brillouin scattering); temperature becomes non-linear at low temperatures (little data on this)
- Traceable (ITS-90) fiber optic thermometry at very low temperatures (cryogenic); standardised calibration techniques
- Phosphor based temperature sensors for 2D Surface measurement of LNG tanks / pipelines (as opposed to current linear DTS measurement)



Downstream Applications – Refinery / Petrochem Gasifier Skin Temperature Monitoring (Reactor Vessels)

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Application Outline

- Refinery / Petrochem vessels where high temperature processes require a refractory lining
- Gasifier - gasification of petroleum coke, bitumen and other heavy residues
- If the refractory lining fails, hot spots occur on the outer surface, which could result in catastrophic failure
- Fiber acts as a passive sensor; no power; attached externally, sensing immune to EMI, vessel skin temperature measurement (fiber limit ~300^{0}C)

Challenges

- Cost effective and complete coverage of the asset, within the limits of the fiber optic sensing cable (bend radius, time to install, longevity, spatial resolution)
- Refinery / Petrochem Gasifier skin temperatures up to 300^{0}C

Downstream Applications – Refinery / Petrochem Gasifier Skin Temperature Monitoring (Reactor Vessels)

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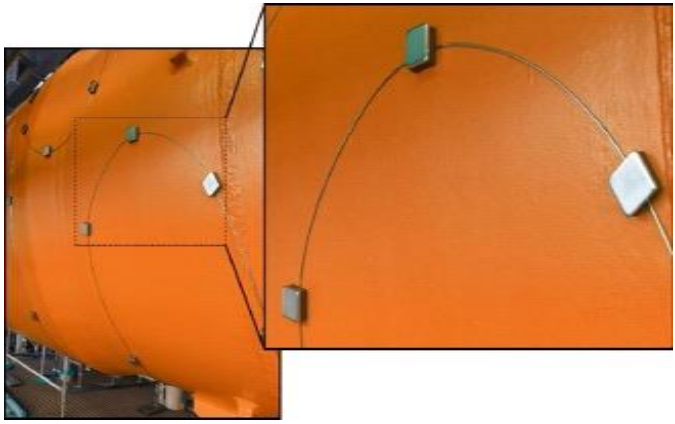
Current temperature measurement methods

- Thermocouples (internal temp. measurement)
- Thermal imaging cameras, fixed and survey
- In low cost applications heat sensitive paint
- Distributed Fiber Optic Temperature Sensing (DTS) helically wrapped around the reactor vessel

Enhanced / new temperature measurement methods

- Low drift Thermocouples
- Traceable (ITS-90) Fiber-based thermometry, single point and distributed up to 660^{0}C
  - Higher temperature Fiber Optic Sensing Cable required 300^{0}C to 660^{0}C range
- Surface Temperature Monitoring (100% reactor vessel surface coverage)

Other Refinery Applications (refractory lined reactors);



- Hydrotreaters / Hydrocrackers (400^{0}C skin temperature)
- Fluid Catalytic Cracking Units (300^{0}C skin temperature)
- Delayed Cokers (530^{0}C skin temperature)
- Sulphur extraction Plants (150^{0}C skin temperature)

Downstream Application – Refinery
Electrical Distribution Equipment - Temperature Monitoring

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Application

Large refineries have 100's of PDC's (Power Distribution Centers) and MCC's (Motor Control Centers)
3,000 Refinery / Petrochemical plants worldwide
Condition Monitoring (temperature measurement); Fire Detection Application

Recent Incident

Pump malfunction caused electrical breaker issue that initiated fire in PDC area

- Safety, Environmental and Plant Shutdown

Customer Request

Ability to continuously monitor temperature of PDC / MCC equipment real-time with historical thermal data (hotspots) comparison over time;

- Improve Safety and Operational Uptime
- Improves predictive maintenance
- Drives preventative maintenance schedules

Downstream Application – Refinery
Electrical Distribution Equipment - Temperature Monitoring

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Current temperature measurement methods

- Periodic (weekly) inspection of PDC's with handheld Infrared Cameras
- No real-time continuous temperature monitoring
- Inconsistent surface location for inspection, Operator dependent
- No historical comparison of Thermal data for early indication of hotspots

Potential Solution

- Surface temperature measurement / Quantitative Thermal Imaging (identification of hotspots)
- Thermal Fingerprinting
- Continuous real-time Surface thermal monitoring
- Comparison of Thermal data over time, CM and Fire Detection

"Protection of both People and the Asset"

Distributed Fiber Optic Sensing Installations (Source : FOSA)

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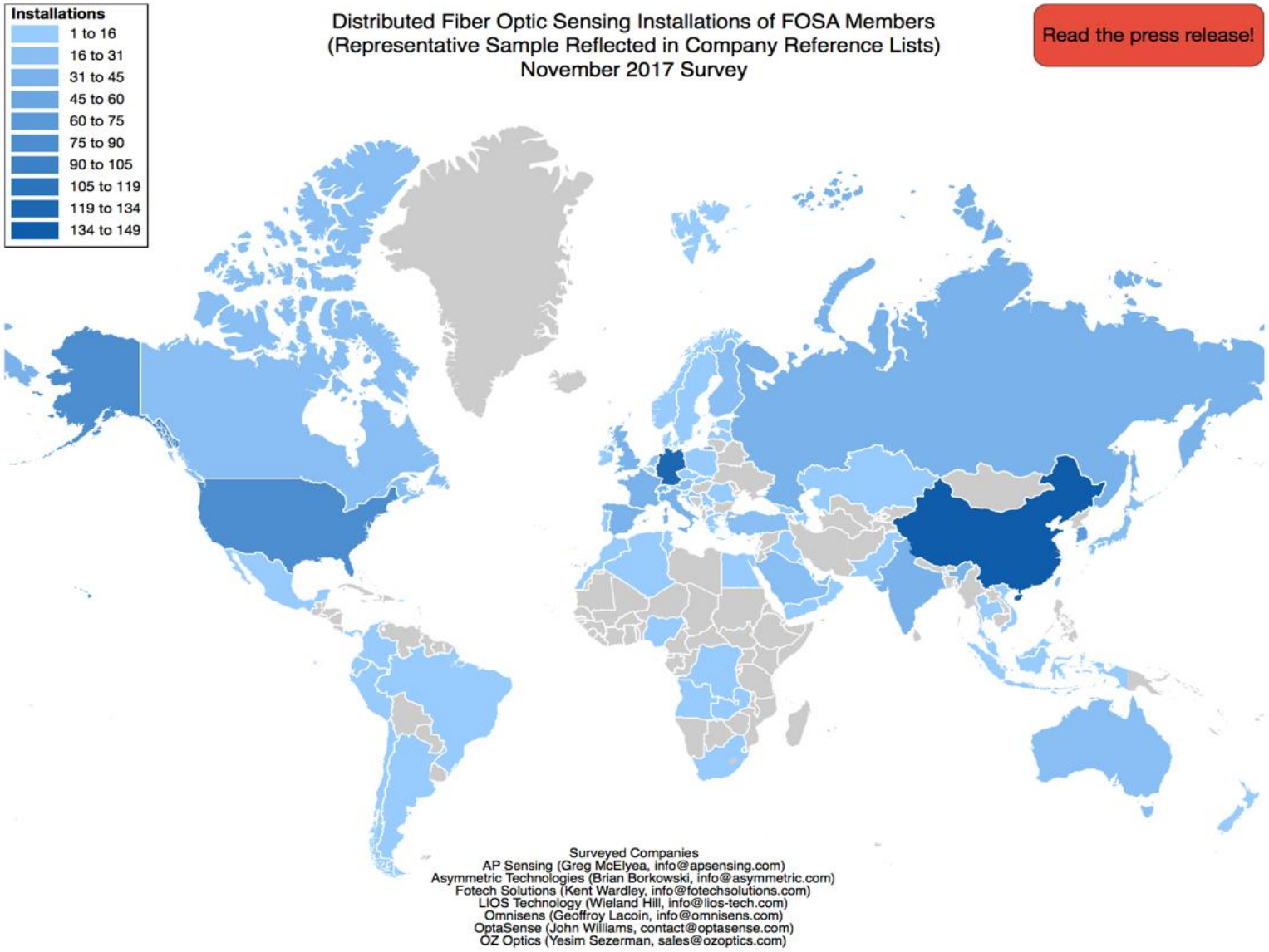

Distributed Fiber Optic Sensing Installations (Source : FOSA)

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- FOSA : Fiber Optic Sensing Association (non-profit, founded 2017)
- 1300+ distributed fiber optic sensing installations worldwide (member companies)
- 75 Countries / 20,000 miles of Fiber Optic sensing cable
- Predominantly Distributed Temperature Sensing (DTS); also includes DSS (distributed strain) and DVS / DAS (distributed vibration / distributed acoustic)
- Primary Applications
  - Power Cable Monitoring (22%)
  - Tunnel Monitoring (Fire Detection) (20%)
  - Pipeline Monitoring (13%)

- Accelerated Market Growth through traceability to ITS-90 for fiber optic sensors / measurement and development of standardised calibration techniques

- Distributed Fiber Optic Sensing – Market Size
  - 2016, $600M Sales
  - 2025, $2B forecast Sales

(Note : IEC 61757-2-2 defines specifications for distributed temperature measurement by a fiber optic sensor)

Global Temperature Sensor Market

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"The temperature sensors market was valued at USD 4.99 Billion in 2016 and is expected to reach USD 6.86 Billion by 2023, at a CAGR of 4.5% between 2017 and 2023.

The chemicals and petrochemicals industries are likely to hold major shares of the temperature sensor market for process…..by 2023"

Source : Markets and Markets, July 2017

- Customer needs in the Oil and Gas Industry are driving both enhanced and new temperature measurement technologies
- Oil & Gas Industry drivers are Safety and Environmental together with improved process control
- Oil & Gas Operators (IOGP) support and drive International Standards (IEC, ISO, API)

Summary (Applications / Temperature Measurement)

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Upstream (SAGD, Geothermal)

Low drift thermocouples (dual-wall)

Slim-line integrated, self-validating thermocouples

Traceable (ITS-90) Fiber-based thermometry up to 660^{0}C (single point and distributed)

Midstream (Pipelines, LNG)

Traceable (ITS-90) Fiber-based thermometry, distributed down to -162^{0}C

Surface Temperature monitoring (phosphor-based)

Downstream - Refinery (gasifiers, reactor vessels) and PDC (Electrical distribution)

Low drift thermocouples (dual-wall)

Traceable (ITS-90) Fiber-based thermometry up to 660^{0}C (single point and distributed)

Surface Temperature monitoring (phosphor-based)

Oil & Gas Temperature Applications ranging from -162^{0}C to 660^{0}C

Questions