Flexible Hybrid Electronics in The Digital Industrial World

September 28, 2020

Nancy Stoffel--GE Research

GE Research

SEE *the future*

MOVE *the future*

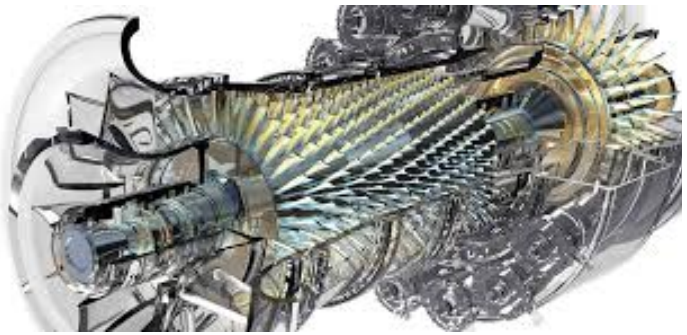
CREATE *the future*

GE ‘s Digital Industrial Portfolio

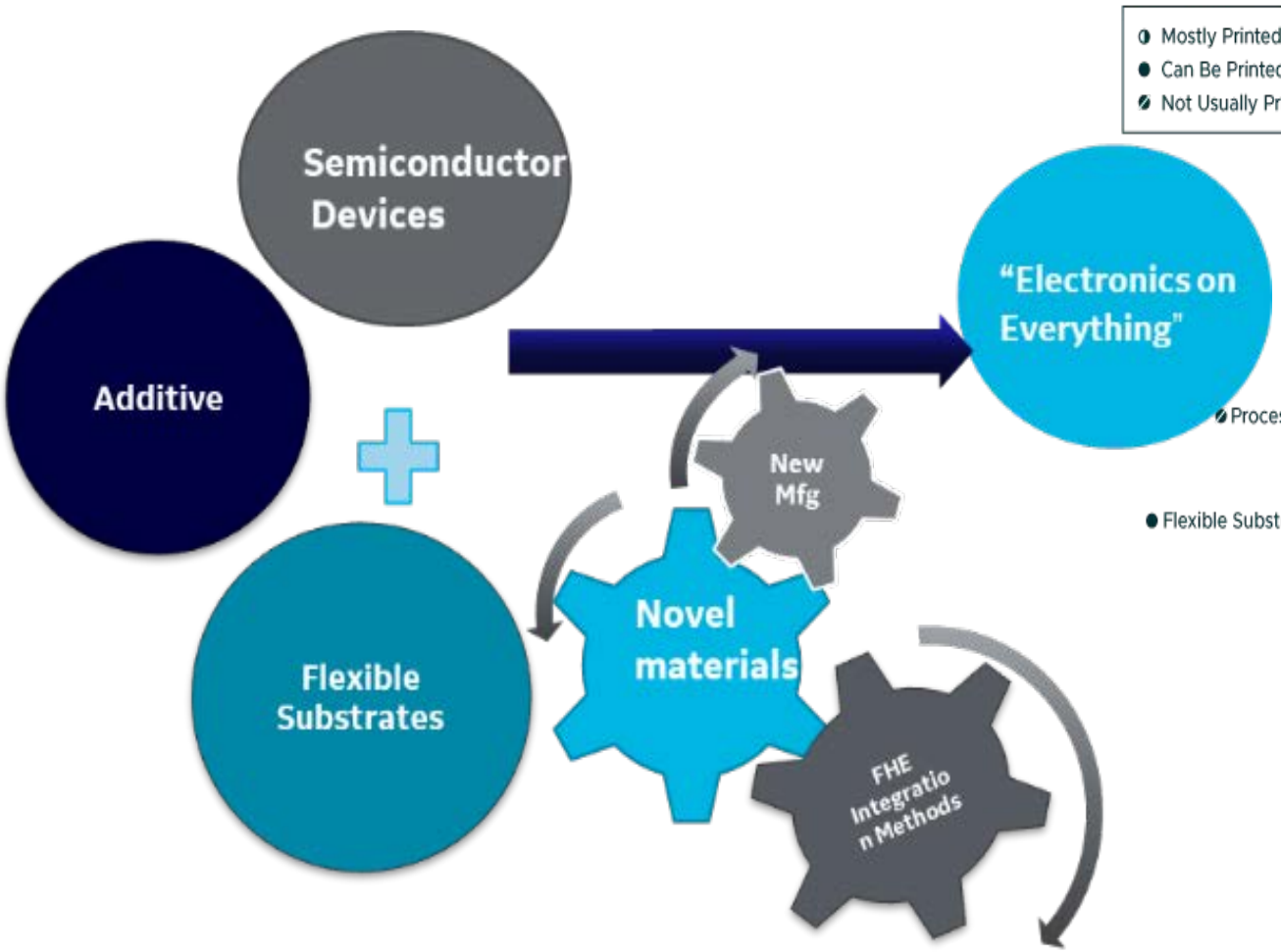
Power Renewable Energy Aviation Healthcare

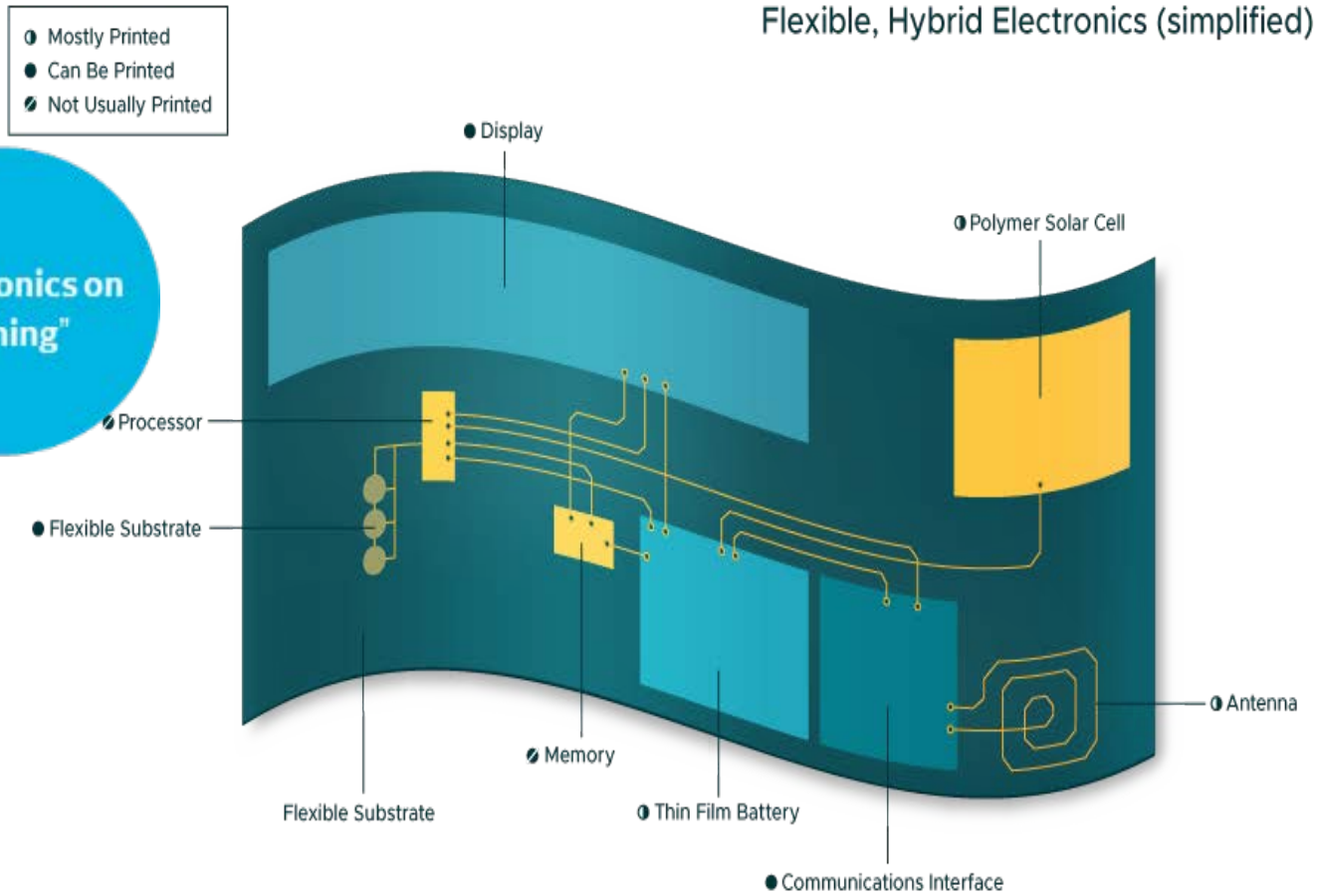
- More than 500 Manufacturing Sites globally
- Customers in over 150 countries
- ~200k Employees






Flexible Hybrid Electronics (FHE): set of technologies focused on integration of sensing, communication, and computational elements to create flexible or conformable electronic assemblies that can adapt to a multitude of geometric and environmental constraints.



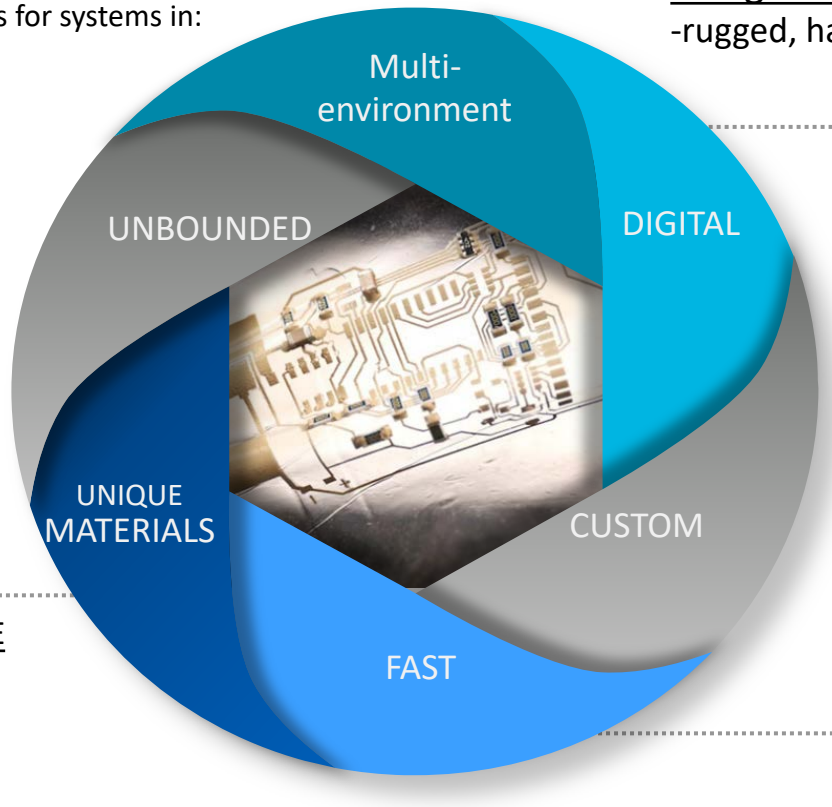


FHE: ELEMENTS FOR SUCCESS

GAME CHANGING

combines previously impossible attributes for systems in:

- form factors
- cost points
- lot sizes
- delivery schedules



Designed for environment

-rugged, harsh industry, body interaction

DIGITAL PROCESS FLOW

Feedback Control Manufacturing,
Virtual Assets, No Tooling Overhead

NOVEL FORM FACTORS

Flexible, Stretchable, 3-D

Lightweight

MASS CUSTOMIZATION

Economic High Mix, Low Volume and
Customized Production

LOW TEMPERATURE MANUFACTURE

Bio Materials, TPU, PET, Compatible

SPEED TO MARKET

Ability to Produce a Complete System Concurrently

Flexible Hybrid Electronics- What Can it Enable?

"Electronics on Everything"

- products that fit the natural forms of our world
- Soft, electronic interfaces on /in body
- Sensing systems designed for their environment through materials and design
- Large format sensing & communication systems

Application Areas:

- Wearables/Implantables for Healthcare
- Wearables for Workers
- Enhanced mechanical edge sensing for GE Products
- Electronics and Sensing Integrated with Structure
- Smart Tracking for Manufacturing, Inventory, Service
- Soft Robotics
- **Sensing of prosthetic arm to give sensory feedback**

What's in it for GE:

- Size weight and power reduction 1/10 size
- 80% reduction in part complexity
- Digital Scaleable Manufacturing
- >10 X cost reduction
- Reliability enhancement

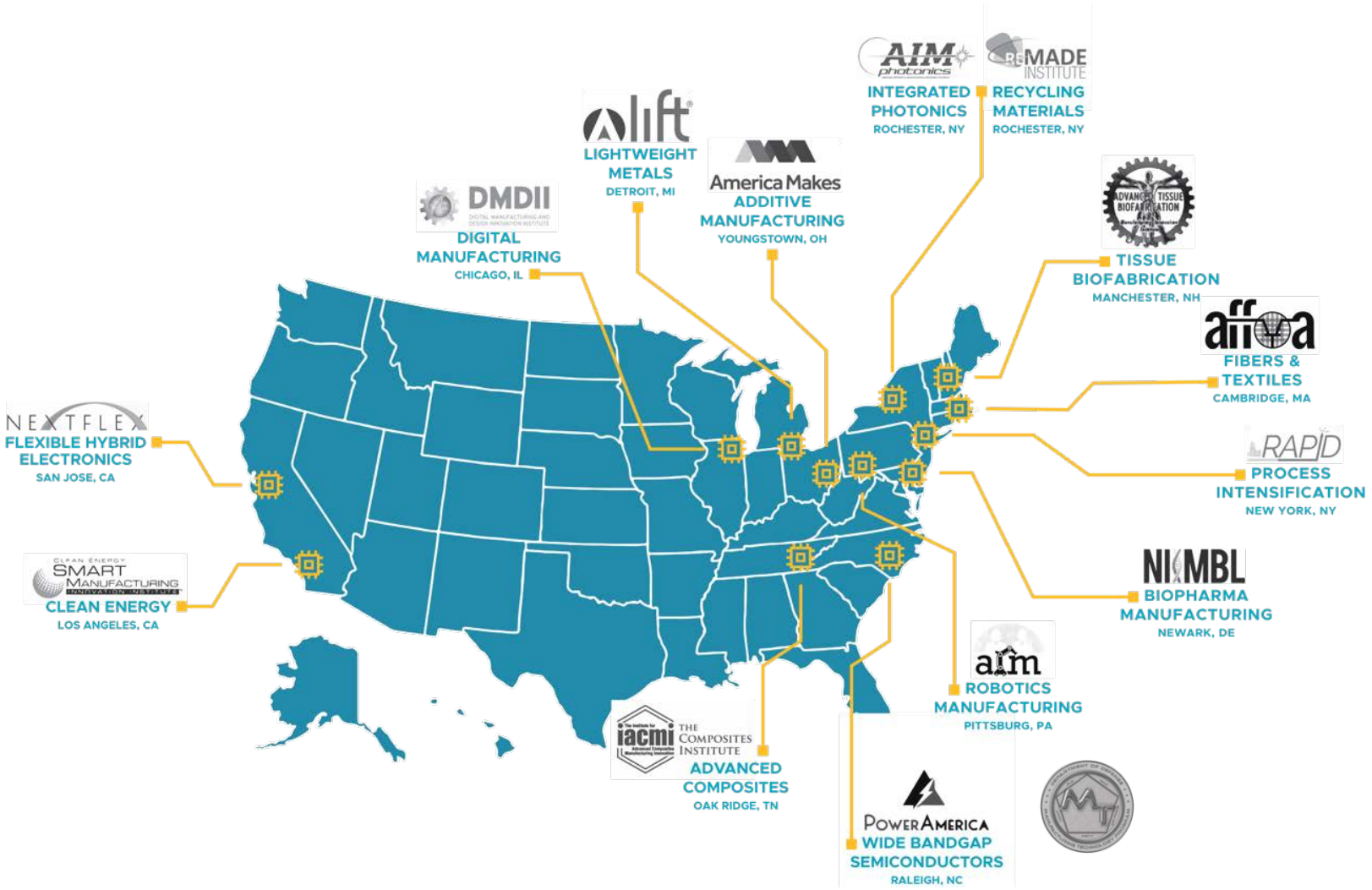
Investment in FHE : A National Priority for Manufacturing Development

Manufacturing USA

- A network of regional institutes, each with a specialized technology focus.
- Secure the future of manufacturing in the U.S. through innovation, collaboration, workforce development, and education.

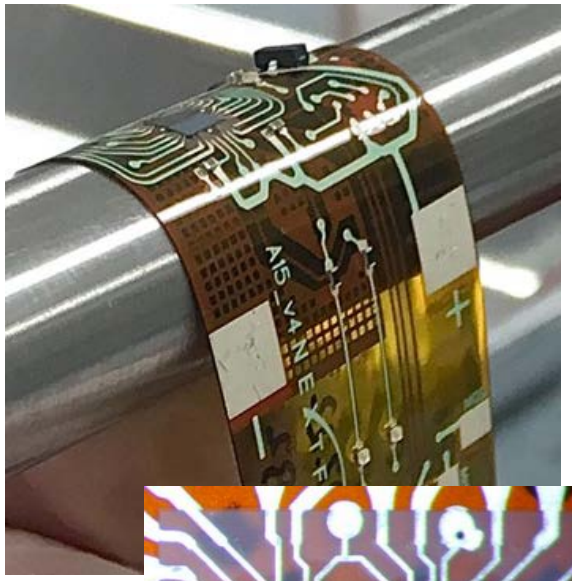
NEXTFLEX

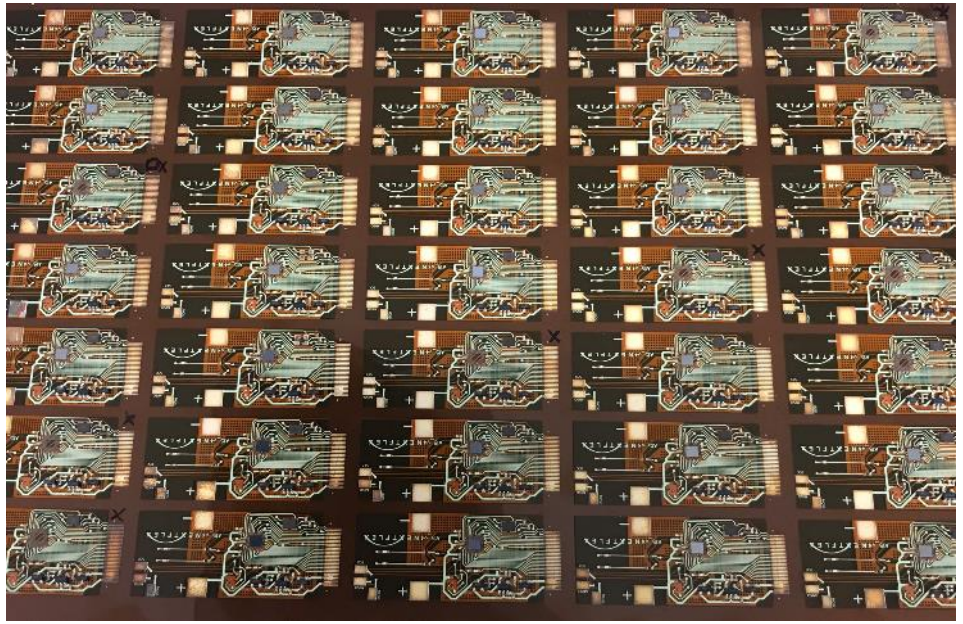
- Focused on FHE
- $75M DOD Invest over 5 years
- Lead: Flextech Alliance, AFRL, ARL
- NYS ESD Match through Binghamton University

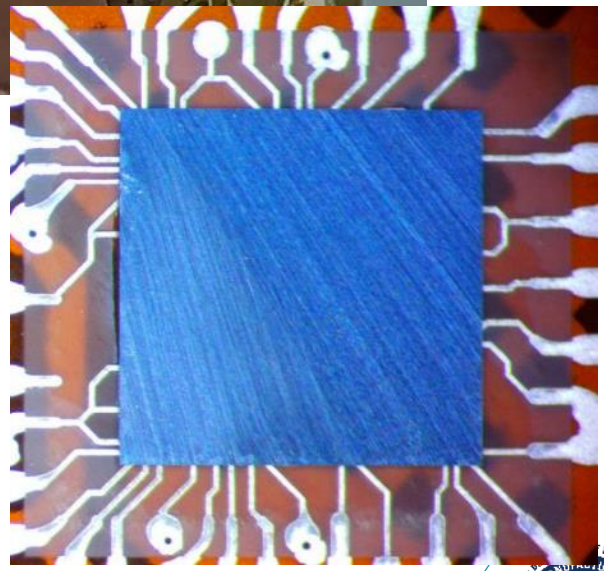


NEXTFLEX AND FLEXIBLE HYBRID ELECTRONICS

- NextFlex is leading a consortium of 100 members across the US to develop and mature this new form of electronics based on additive manufacturing and incorporation of thin, bare die.





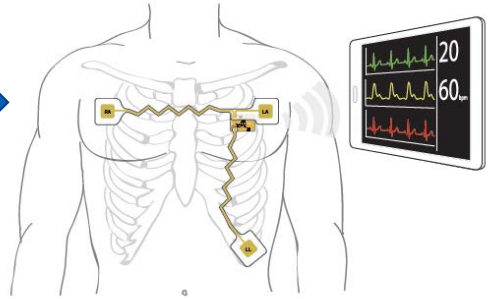


Change in Form Factor of Sensors: Rigid to Flex to Soft

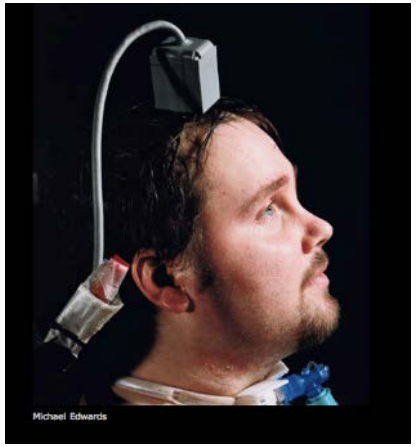
Conventional ECG

untethered

disposable

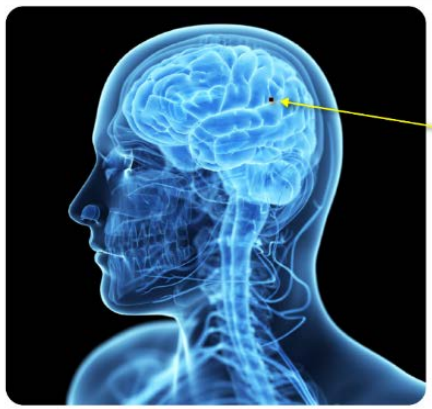


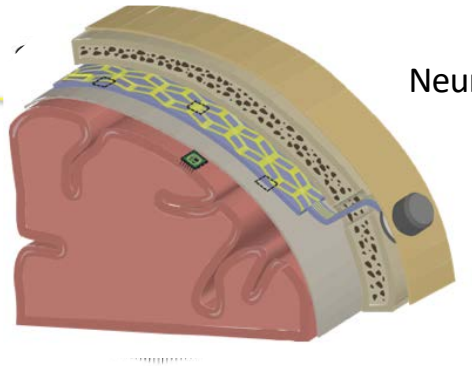
BrainGate Neural
Interface enable
control of robotic



http://www.terasemmovementfoundation.com

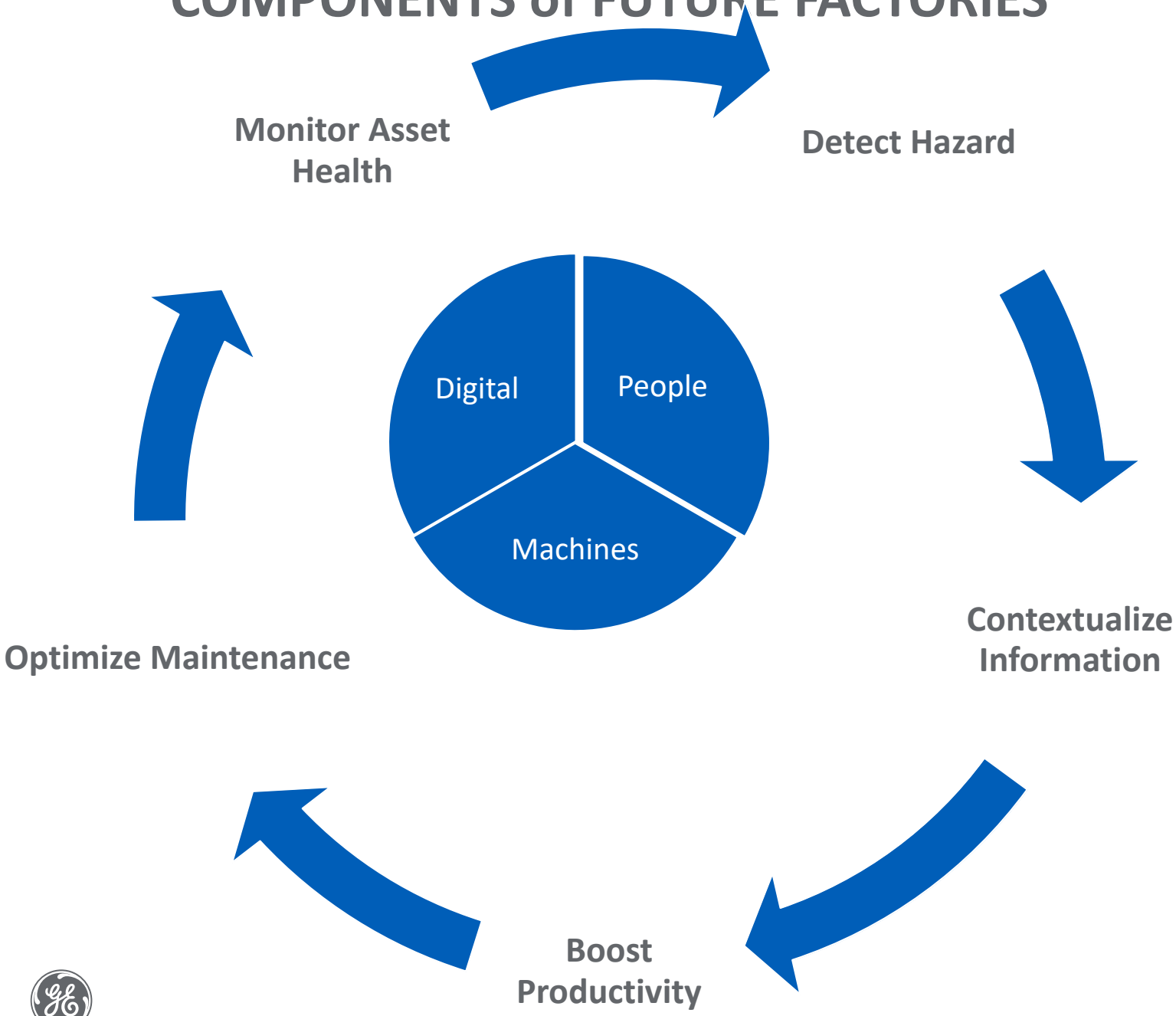
Soft electronic implants for low profile chronic Implantation



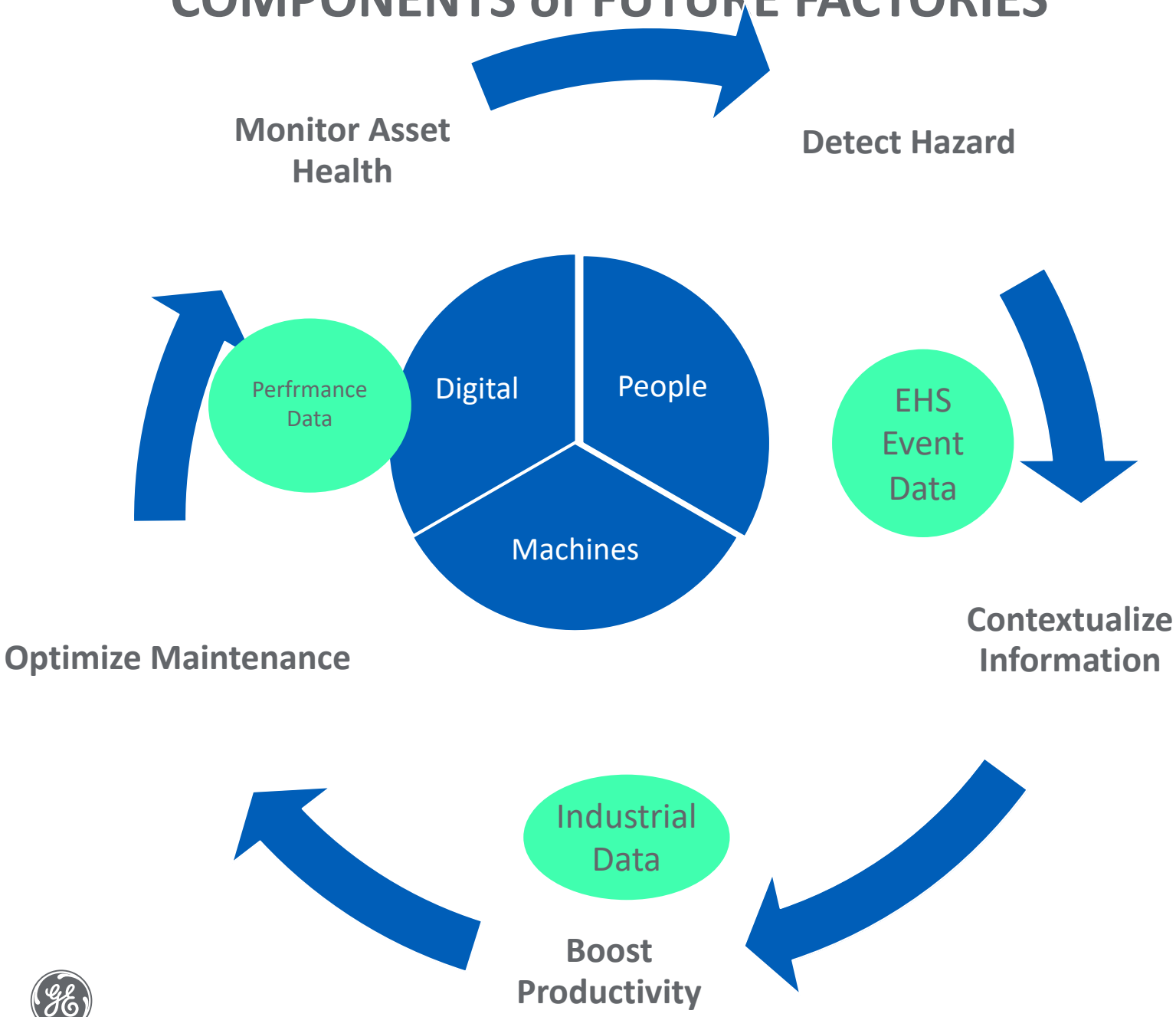


Neural

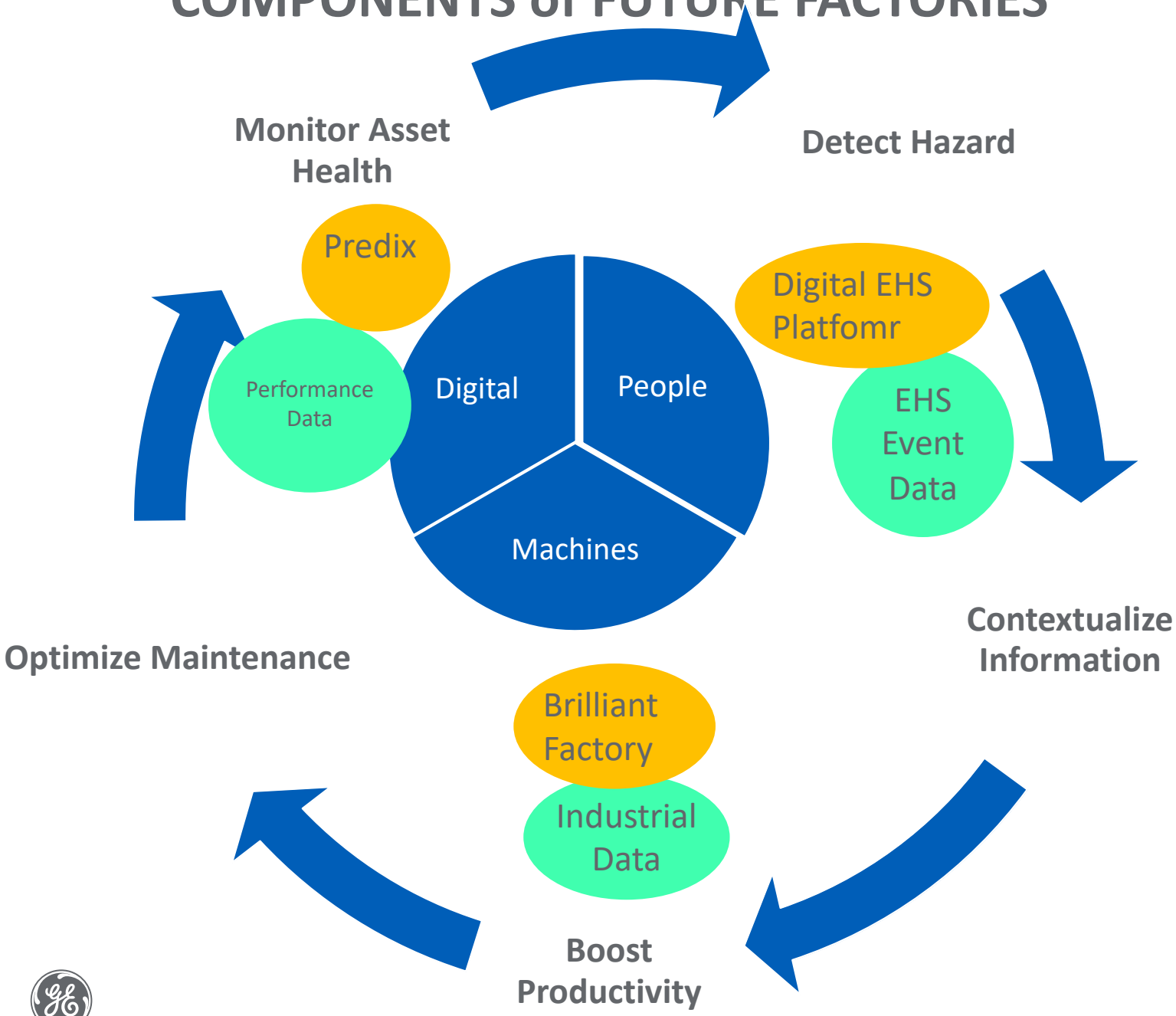
COMPONENTS of FUTURE FACTORIES



COMPONENTS of FUTURE FACTORIES



COMPONENTS of FUTURE FACTORIES



BRILLIANT FACTORY

- Modern Design Practices
- Manufacturing Production Planning
- Production Process Optimization

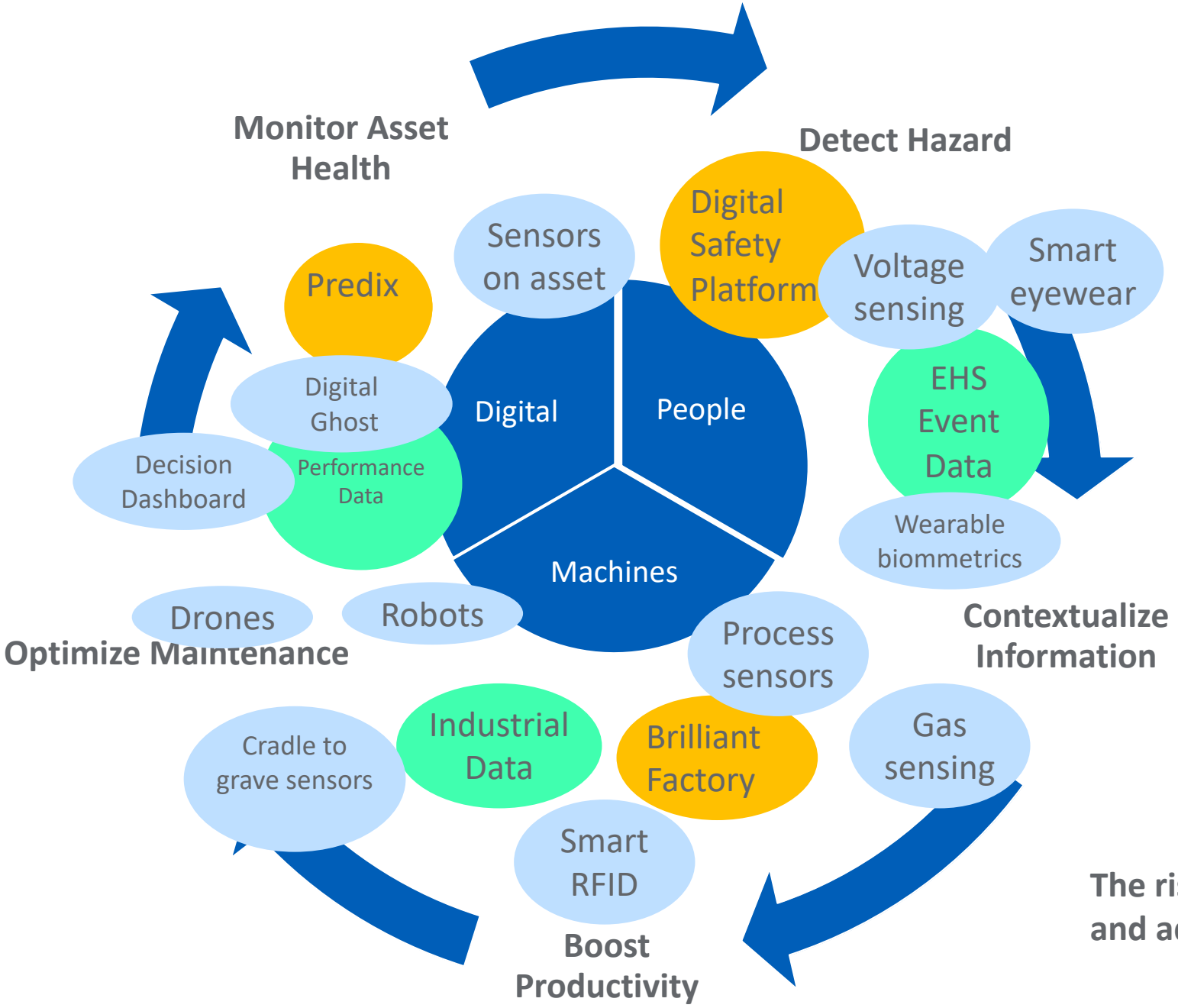
PEOPLE- ONEHS Digital

- Safety
- Productivity

Ongoing Field Support -PREDIX

- SHM
- PHM
- Optimized Control for Efficiency or Life
- Feedback to Design and Manufacturing

COMPONENTS of FUTURE FACTORIES



BRILLIANT FACTORY

- Modern Design Practices
- Manufacturing Production Planning
- Production Process Optimization

PEOPLE- ONEHS Digital

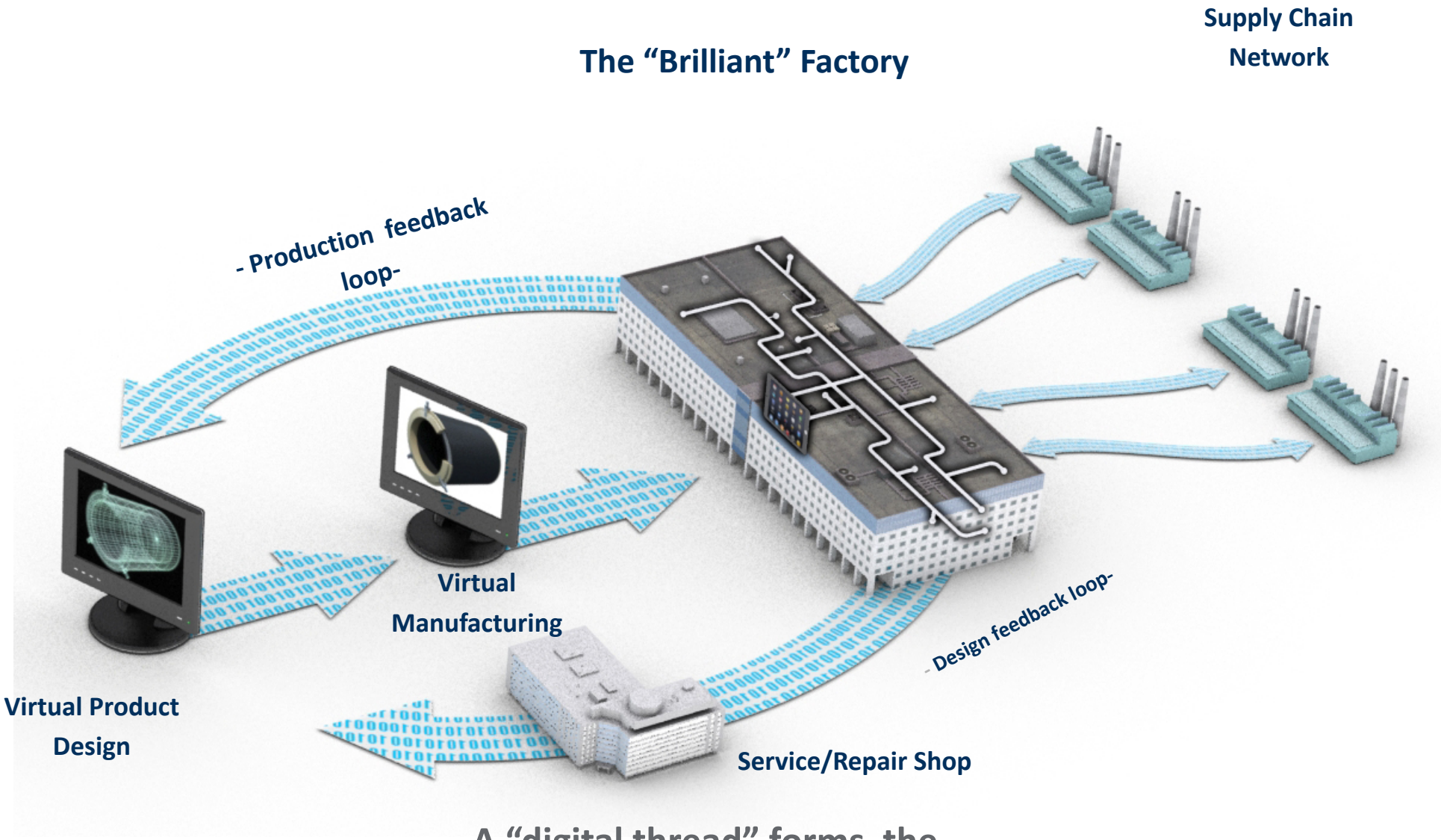
- Safety
- Productivity

Ongoing Field Support

- SHM
- PHM
- Optimized Control for Efficiency or Life
- Feedback to Design and Manufacturing

The rise of robots, automation, data analytics and additive technologies are transformative

Brilliant Factory



A "digital thread" forms the
21st Century Assembly Line for Smart Manufacturing

Advanced Manufacturing Transforms the Entire Value Chain

Industrial Internet meets manufacturing

10-50% cost out
20-70% ↓ cycle time
10-50% ↑ yield

VIRTUAL DESIGN & MANUFACTURING

- Should-cost
- Producability advisors
- Virtual manfacturing
- Collaboration

2-4X ↓ cycle time
50-70% ↑ intros
2X yield

SMART FACTORIES

Sensor Enabled Automation

- Novel process prototyping
- Informatics
- Model-based manufacturing
- Condition Based Maintenance
- In Line Inspection
- Process Optimization

Factory Optimization

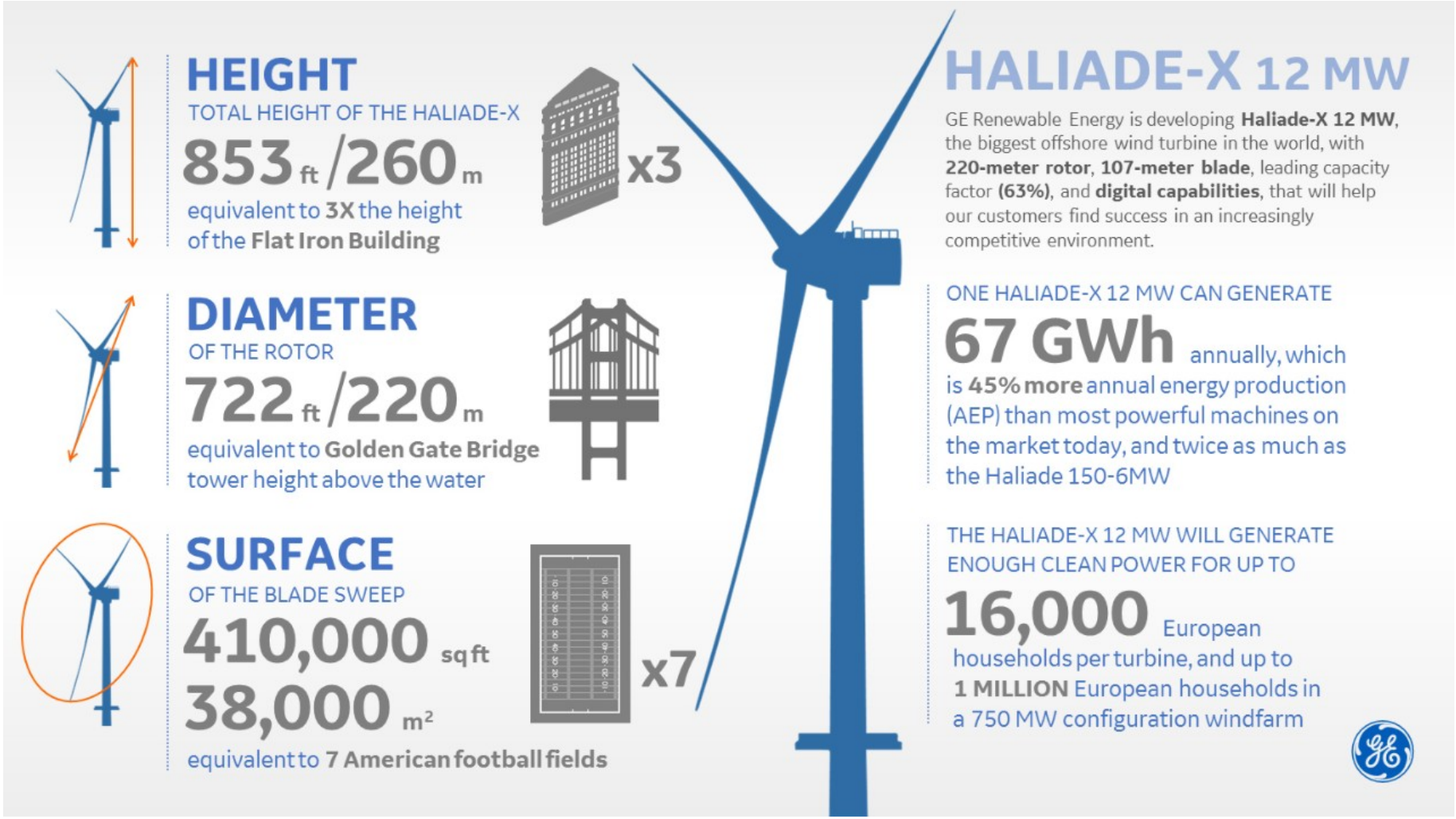
- Tracking of parts, product
- Real time optimized factory and optimized system design
- Bottleneck detection
- Data-driven manufacturing models

7-15% ↓inventory
3-5X predictability
40% ↓ downtime

SUPPLY CHAIN OPTIMIZATION

- Real-time analytics
- Visibility
- Predictive maintenance
- Connected systems

Challenges of Renewables Manufacturing



- Longer, lighter blades
- Increased blade performance
- Lower cost of energy
- Production increase
- Off-shore sites
- Repowering and extension of Service Life
- Damage assessment
- Adaptive control: performance, asset life, weather, wildlife

FHE Enabled Cradle to Grave Composite Structural Health Monitoring

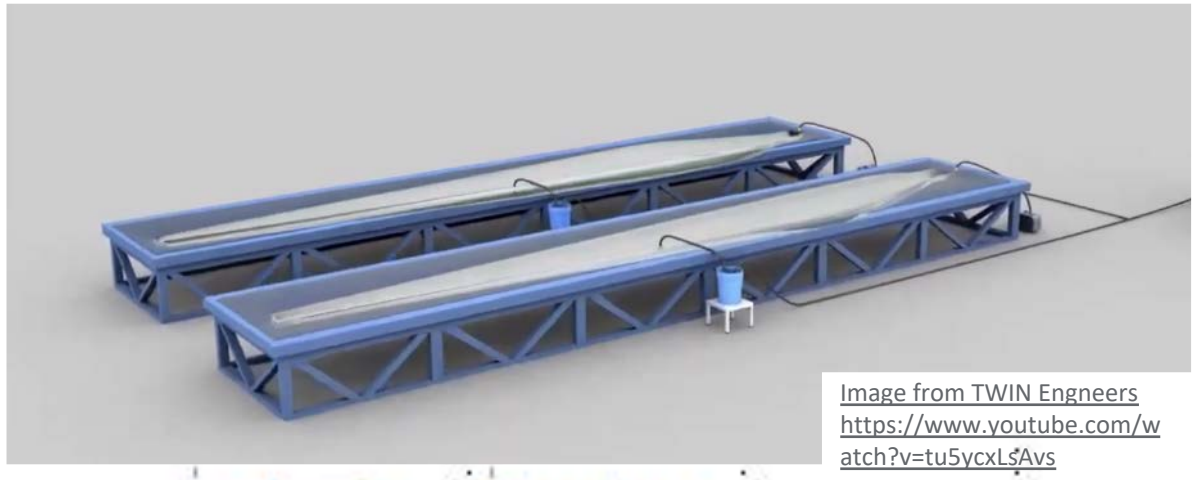
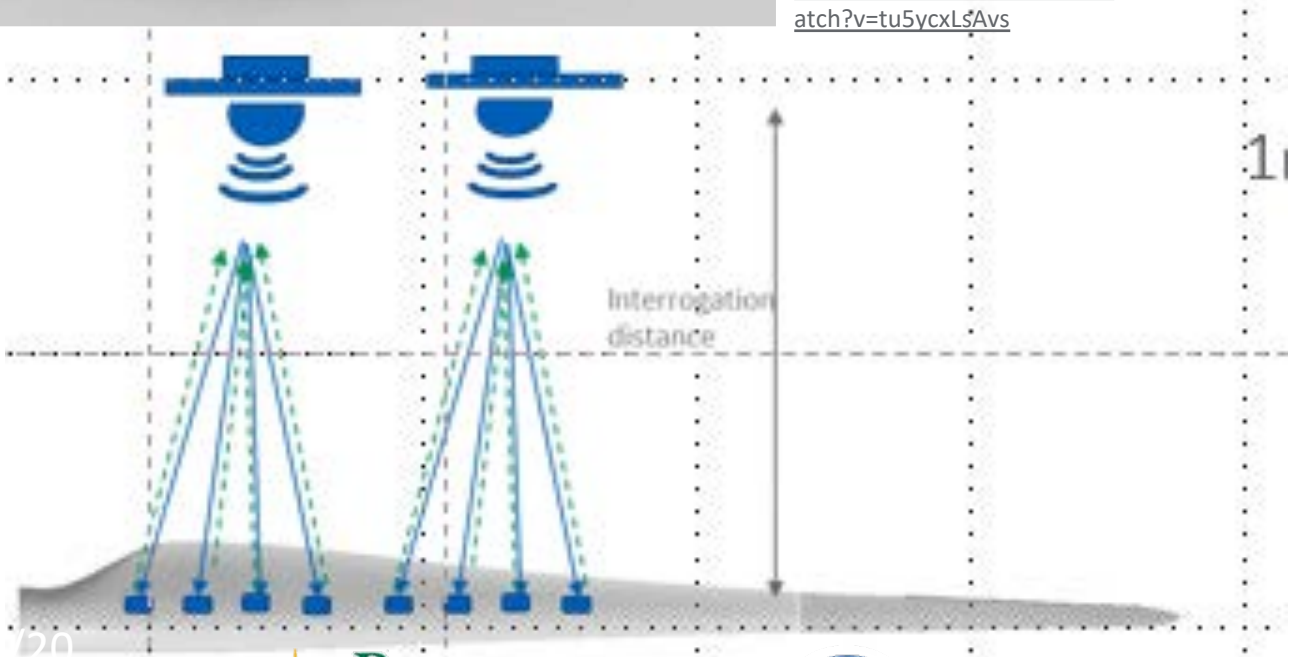


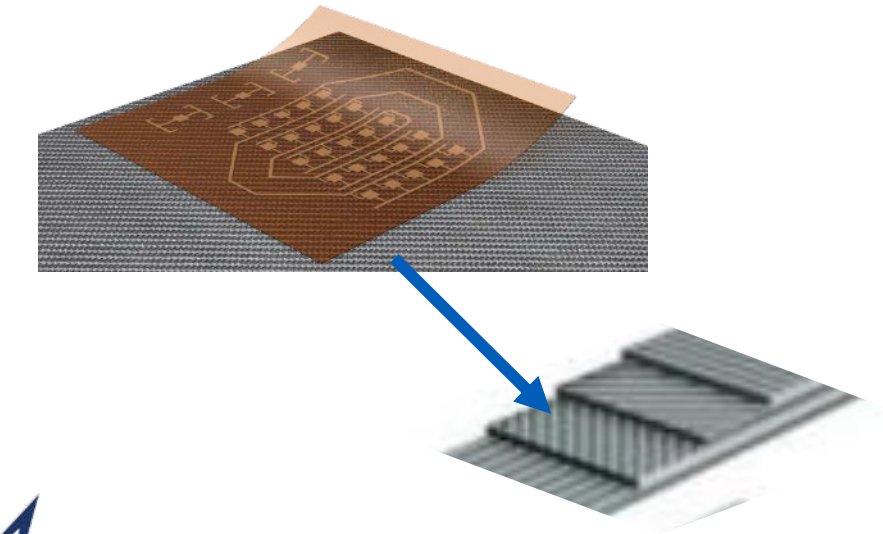
Image from TWIN Engneers https://www.youtube.com/watch?v=tu5ycxLsAvs



A scalable network of passive sensing patches that can be embedded or placed on composite structures and provide input on process during manufacturing.

Temp, strain, dielectric measurements inform:

- Infusion process
- Cure process
- Prevent rework



Sensor embedded into or onto composite

Georgia Tech | Binghamton University, State University of New York | GE | Sikorsky, A Lockheed Martin Company

Sensor Embedded into Structural Composite for Operation

Sensors provide state awareness enabling:

- closed loop operational control
- structural health monitoring
- reduce costs and improve safety.
- Many applications possible

Passive Sensor Advantages

- Simple, low profile sensor
- Inexpensive
- No battery or wiring required
- Relieves Lightning strike issues
- Eliminates complexity of wiring
- Reader can be integrated into structure
- Very large dynamic range of measured strain (5-10,000+ ustrain)
- Rugged operability near conductors and/or clutter
- Easy integration with “zero-power” backscattering techniques

Georgia Tech

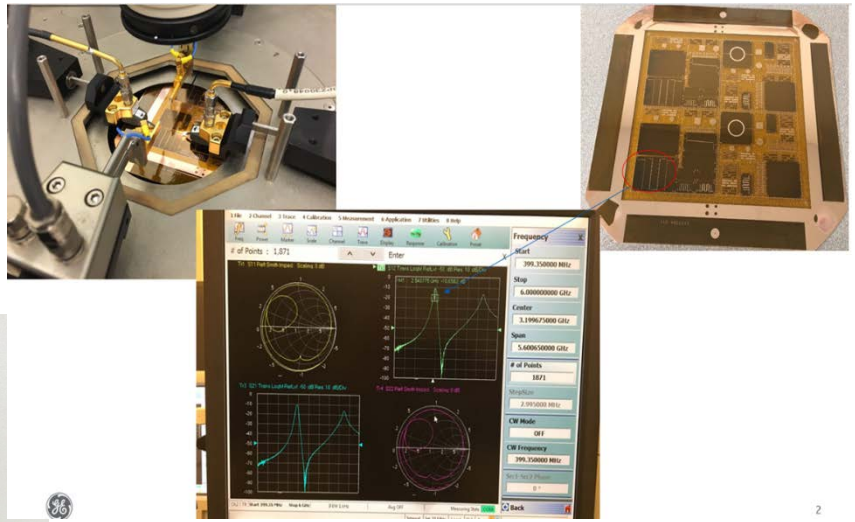
BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK

SIKORSKY
A LOCKHEED MARTIN COMPANY

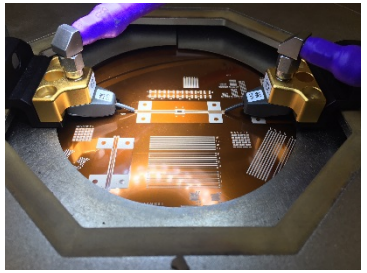
Printed RF Systems

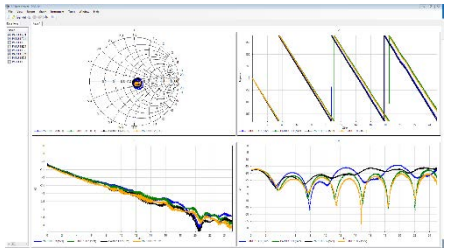
Interconnect, Passives and Embedded Die

Nextflex PC1.0 & 3.2

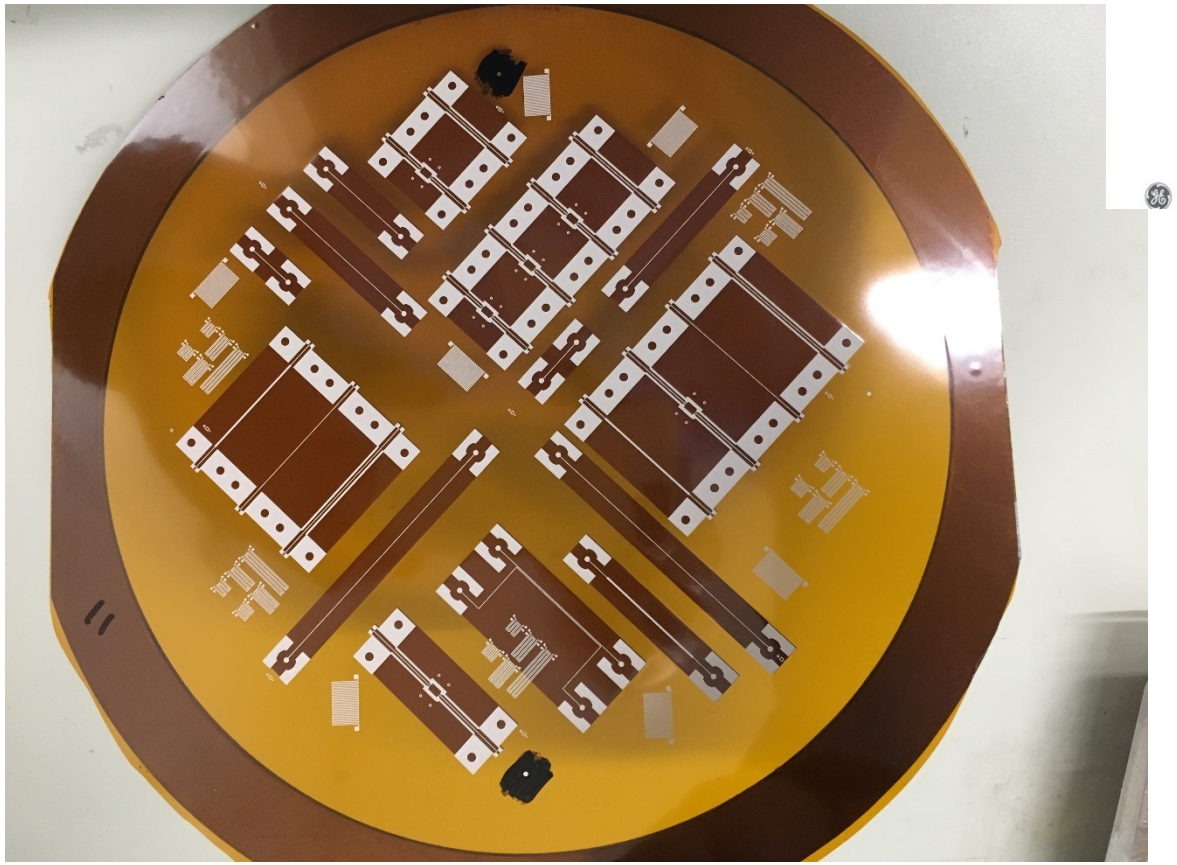


PC1.0- Topside Print Only





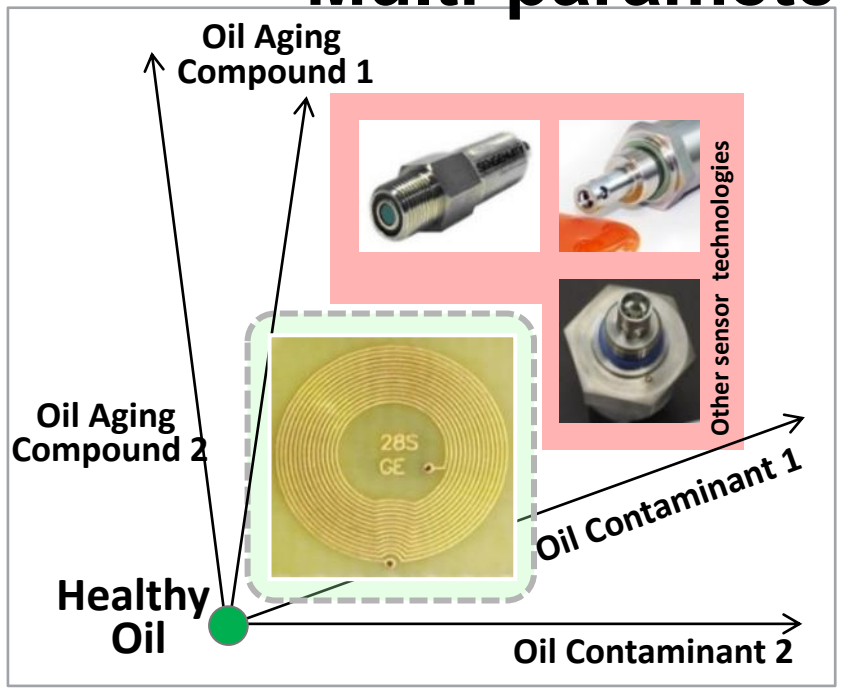
Embedded die
performance to >25Ghz



PC 3.2- Double side printed RF circuitry with printed vias and embedded die

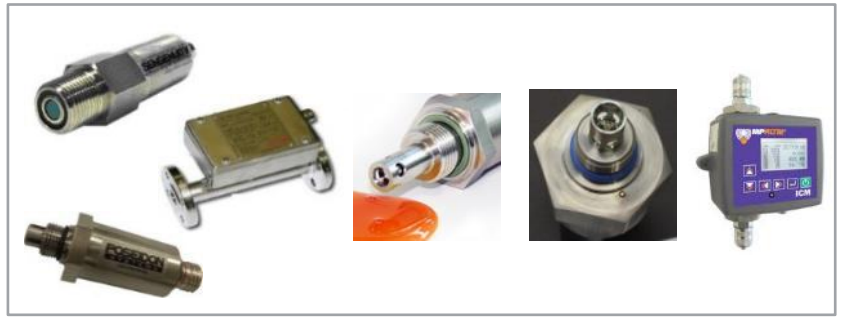
Enables:
Lower Cost
Digital Design = Quick Turn
Affordable Antenna in Package
Affordable Ultrathin Packaging
Conformal Active Arrays
Deployable Arrays

Industrial Equipment Maintenance: Multi-parameter oil health sensing



Value proposition of GE solution

- ✓ Independent quantitation of oil aging and external contaminants by sensor design + analytics
- ✓ Electrical resonant sensor for early diagnostics of industrial fluids



Limitations of existing sensors

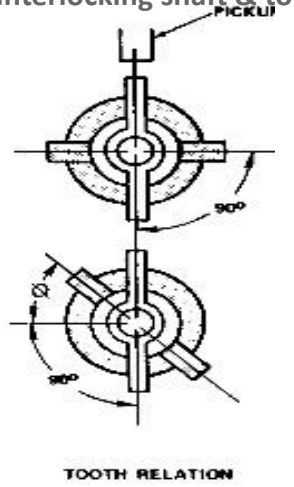
- ✗ Poor sensitivity prevents prognostics
- ✗ Cannot discriminate oil aging (total acid number, TAN) vs external contaminants (water, fuel)

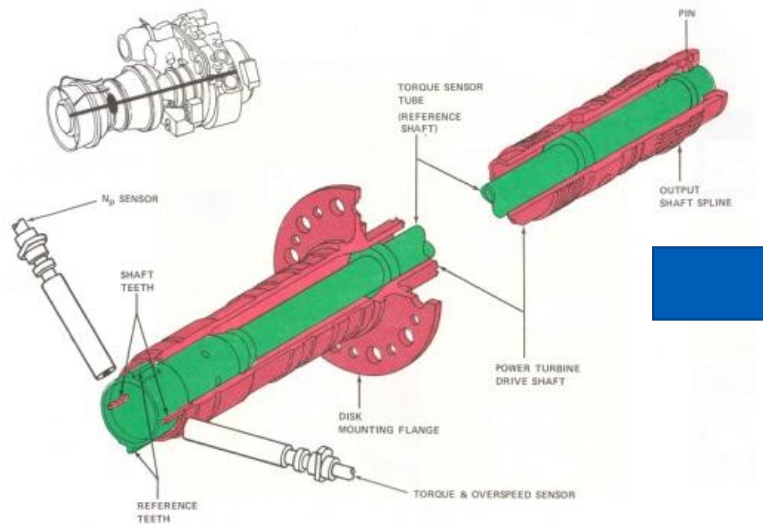
Potyrailo, R. A.; Tokarev, I.; Go, S.; Ottikkutti, P.; Kuzhiyil, N.; Mihok, J.; Anzini, C.; Shartzer, S. accepted, **2018**

Asset Monitoring for Optimized Operations in Aviation Extending to Industrial Use through FHE

Reference Shaft Method

T700: System Accuracy ~ 3-5 %
interlocking shaft & torque tube,





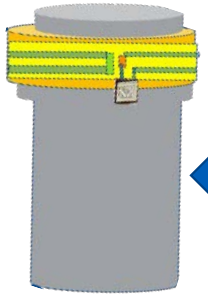
Measuring Torque allows optimized operations, and extended life

SAW Torque Sensor

- passive: no battery or wired power
- Improved accuracy
- Only sensors in harsh zone
- Electronics in benign zone
- Low Mass –does not affect engine dynamics

OC 1.0 Peel and Stick Sensor on Asset
Wider Adoption, Scalable, Reliable
Rotating or reciprocal shafts

- >2X improvement in G capability
- 70% profile reduction
- >10X increase in asset size supported
- Reduce Assembly steps from 19 to 4
- Reduce part count by 80%
- Reduce Shaft Rework by 20%
- Reduce qualification costs & time by 80%
- Reduce NRE time by 50%



Extend to power

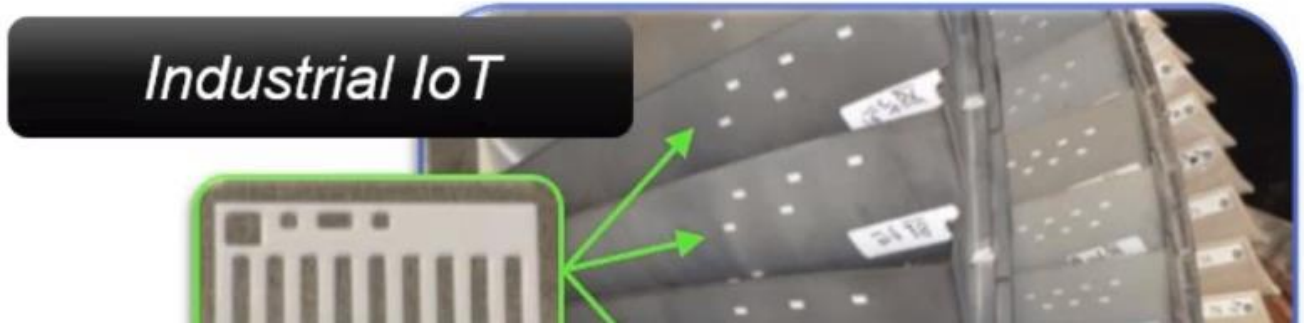
O&G, transportation

Developed for Helicopter Engine Program for Military Use

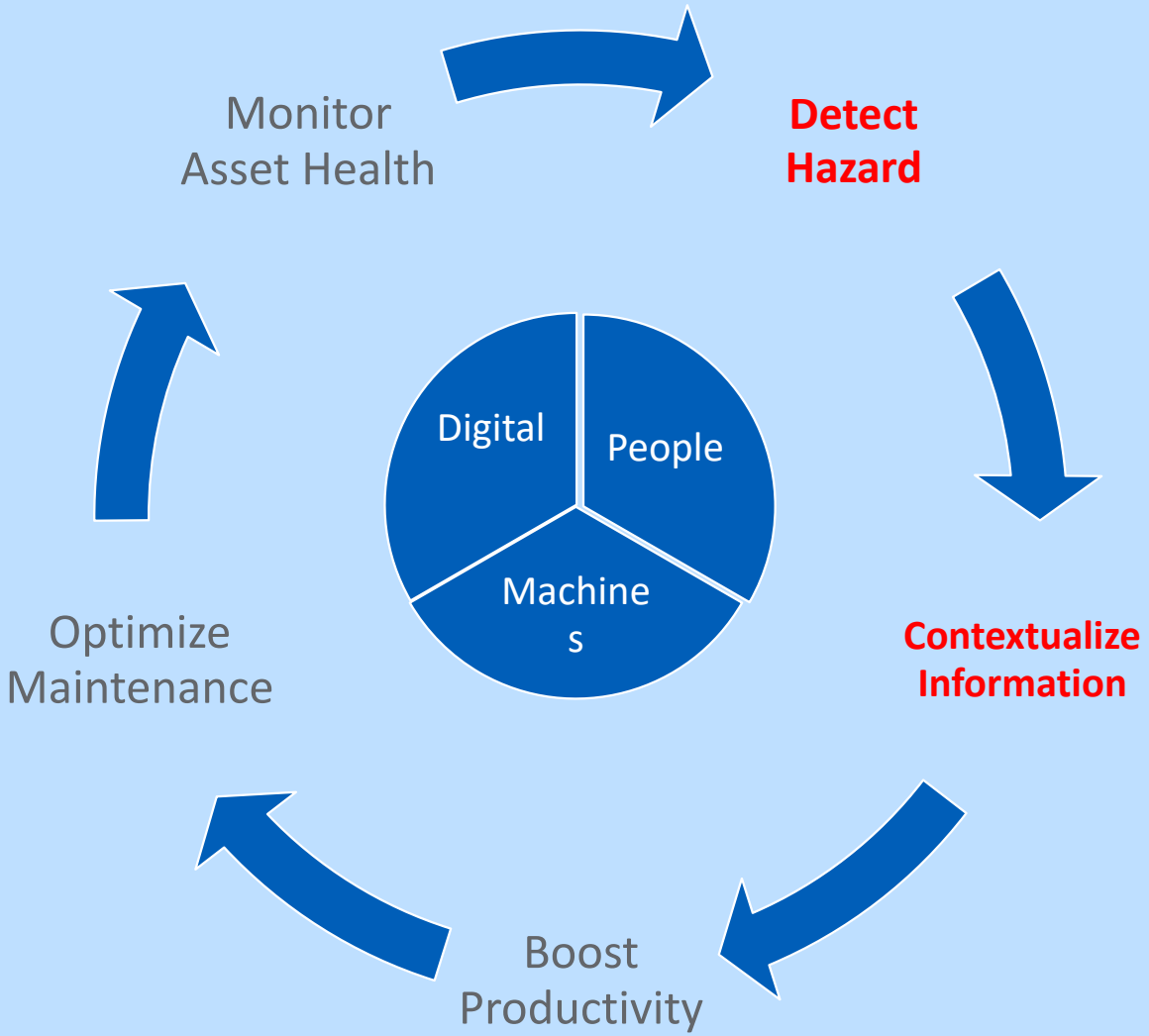
- Requires Torque sensing with >1.5% accuracy
- SAW method ~ 2X as accurate as previous solutions
- 3.5 lbs wt savings
- Eliminates 9% of unplanned engine removals

PRINTING ON 3D SURFACES: CREEP SENSOR IN POWER

- 3D Sensors Condition-Based Maintenance
  - Fully Automated Robotic WorkCells
  - Printing Serialized Strain Sensors
  - Collected Data Analyzed on GE Predix Cloud
  - Few dollars to print, potentially saves $10,000's in reducing maintenance Costs
  - Production Capacity: ~1 Million Sensors/year



COMPONENTS of FUTURE FACTORIES- Focus on People



BRILLIANT FACTORY

- Modern Design Practices
- Manufacturing Production Planning
- Production Process Optimization and Control

PEOPLE- ONEHS Digital

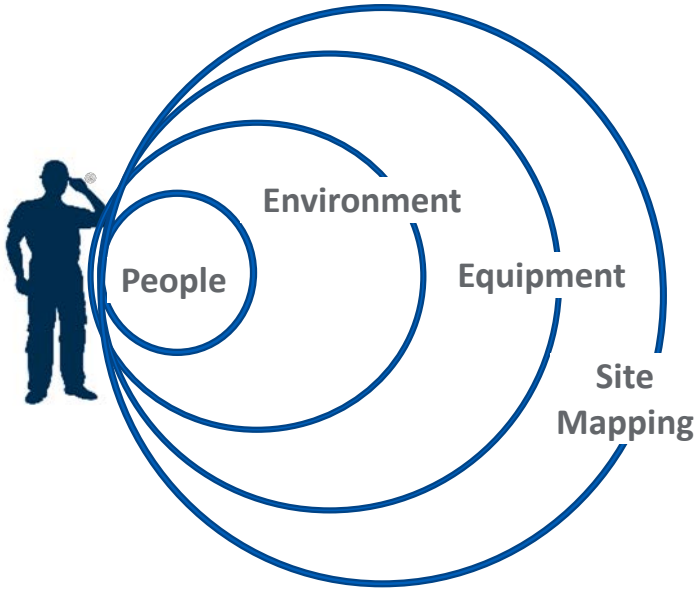
- Safety
- Productivity

TESTING/Quality Assurance

Ongoing Field Support

- SHM
- PHM
- Optimized Control for Efficiency or Life
- Feedback to Design and Manufacturing

5 Year Digital EHS Roadmap- Industrial Safety



2018

Predictive Analytics

Digital Twin

HiPo

Hazard Identification

Event Modeling

Artificial Intelligence

Vision

Language

Virtual Assistants

Planning

Exoskeletons

Smart Glasses

Lone Worker Wearables

IOT IH Monitoring

Inspection Robots

Hazard-Sensing Bands

Gensuite Simplification & Integrations

Spotfire EHS Performance Dashboards

Intelligent Machines

Block Chains

Brilliant Factories

UAVs

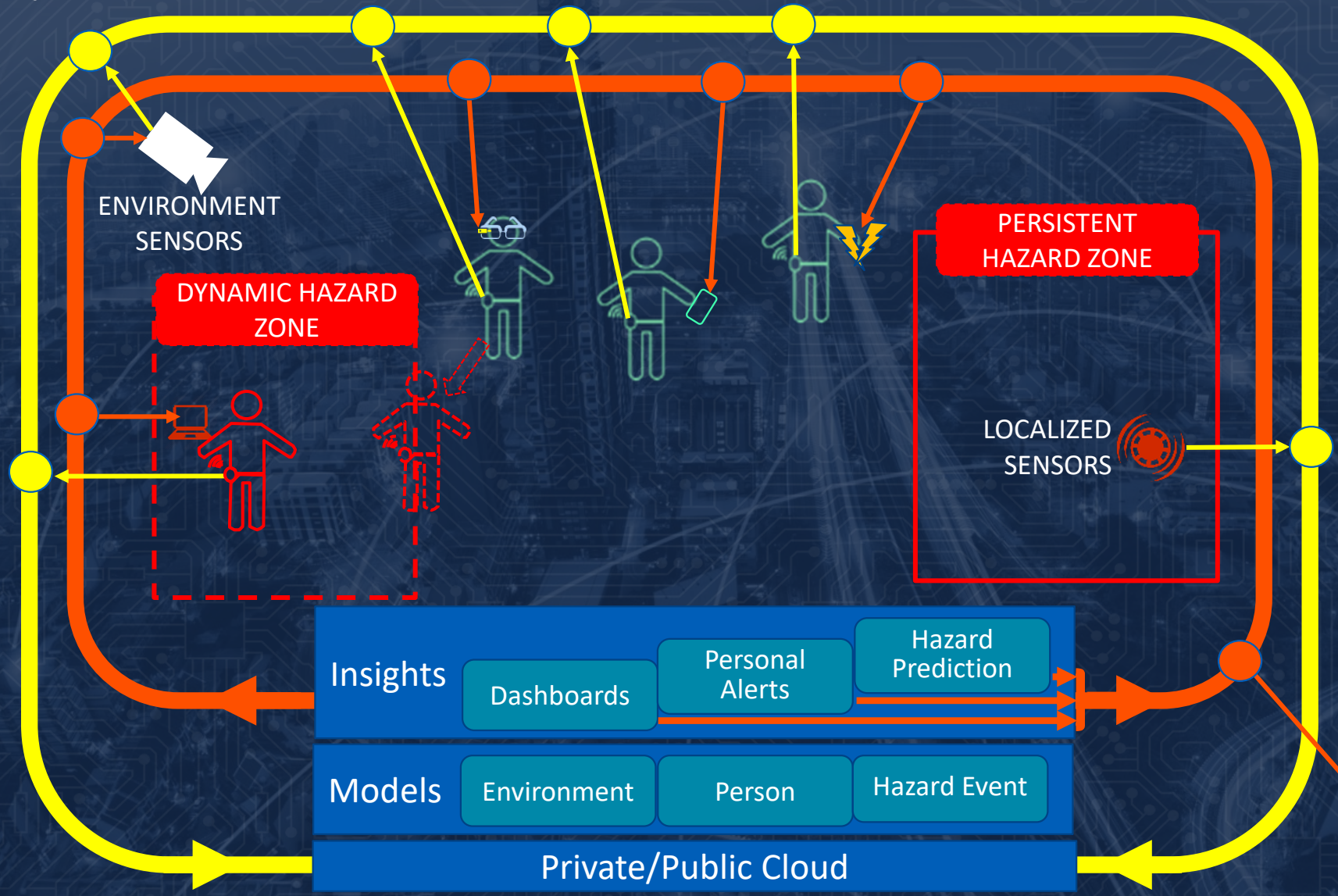
Smart Materials

EHS PLATFORMS

WEARABLES & BOTS

EHS SMART ECOSYSTEMS

Occupational Safety System Digital Platform



- Accurate & reliable Sensors
- Flexible SW Platform
- Robust Connectivity
- Outcome based Analytics

Example Sensors / Information Source

GE Gas, Voltage, Sweat, Biometric

Non-GE Watch, Camera, Exo-suit, Smart Glasses, Weather Data

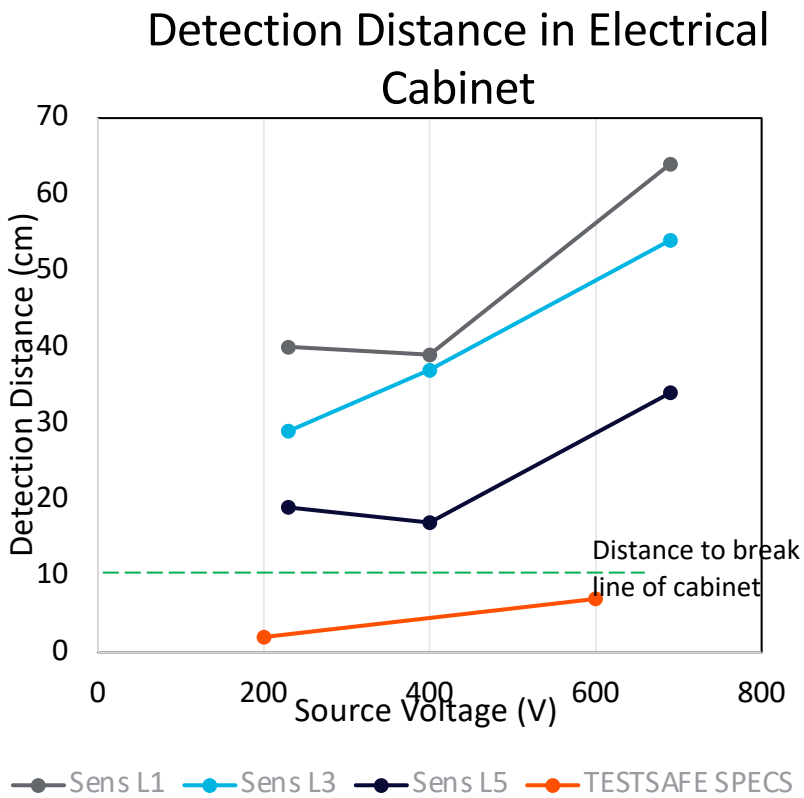
Occupational Safety Wearable: Voltage Sensing Wristband Designed to Ale
Users of AC Voltage Sources

A wristband that:

- ***Senses and alerts user to the presence of electrical fields***
- ***"Wear and Forget"***
- ***Supplement to safety procedures and LOTO***
- ***Prevents incidents and accidents***
- ***Designed as added safety function for service and repair***
- ***May be useful for first responders***

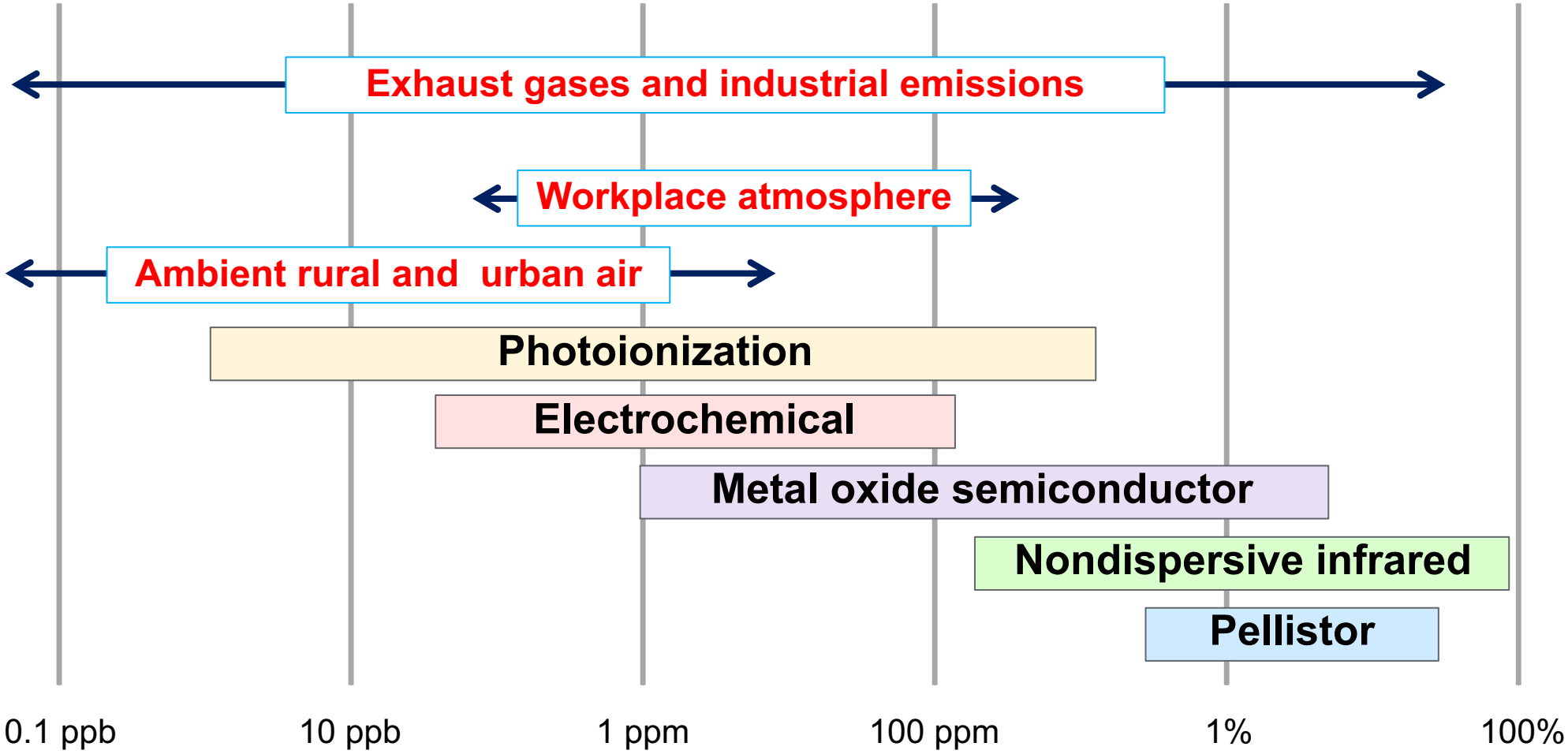
- Power consumption/battery life: >16 hours
- Rechargeable
- User adjustable Sensitivity Settings
- Omnidirectional Detection
- Sensitivity: min 80cm @110 VAC
- Voltage to detect : Required 100 VAC to >1kVAC
- Frequencies: 50Hz, 60 Hz
- Alert mode: audible, visible, vibratory
- Sensitivity Adjustment

- Next Generation Band has:
  - Wifi/Bluetooth connection to allow notification and mapping
  - Worker Down Function



27

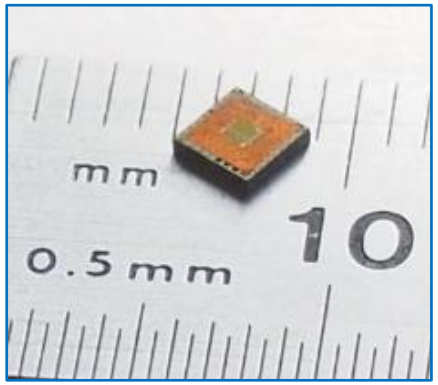
Main available sensors for gaseous pollutants



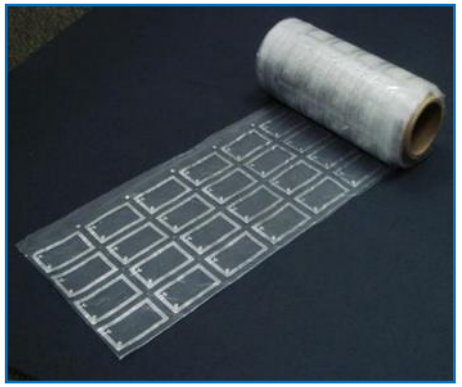
Szulczynski, Gebicki, *Environments* **2017**

Designs of resonant RF and RFID sensors

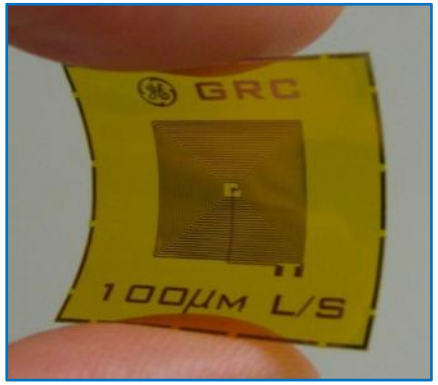
RFID tags



Roll-to-roll

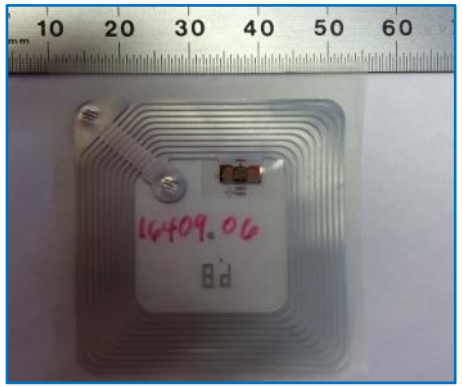


Flexible



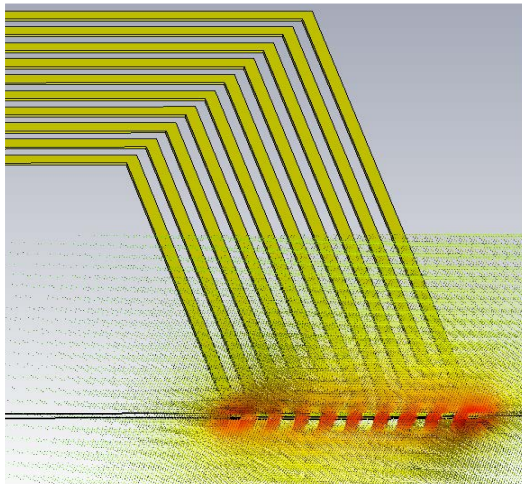
Potyrailo, Mirsky, *Chem. Rev.* **2008**
Potyrailo, Surman, Nagraj, Burns, *Chem. Rev.* **2011**
Potyrailo, Naik, *Annu. Rev. Mater. Res.* **2013**

Complementary

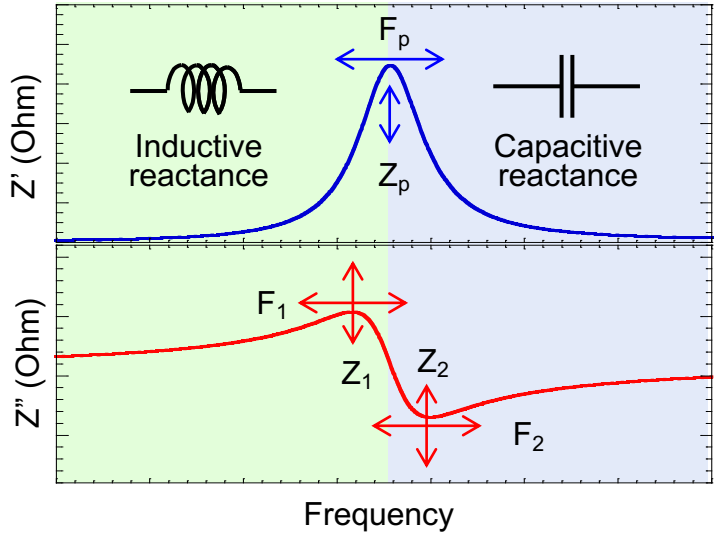


Potyrailo, *Chem. Rev.* **2016**
Potyrailo, *Chem. Soc. Rev.* **2017**

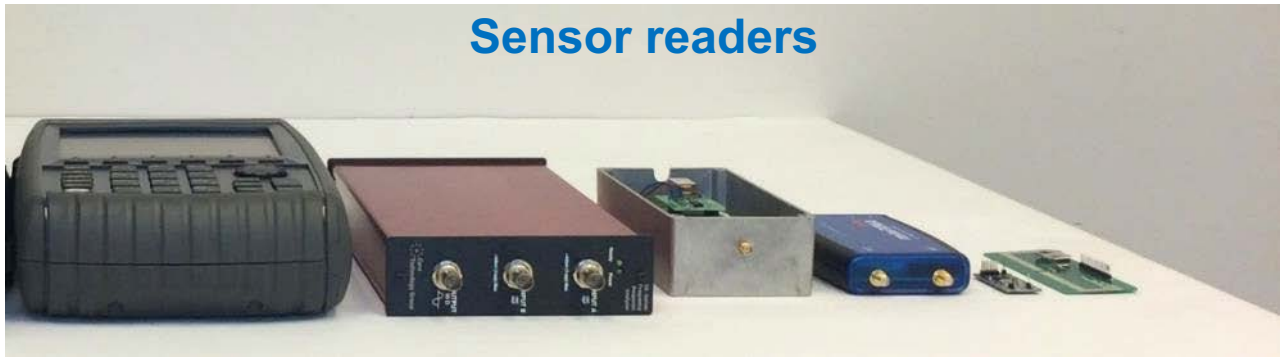
E-field interactions



Measured spectrum



Sensor readers

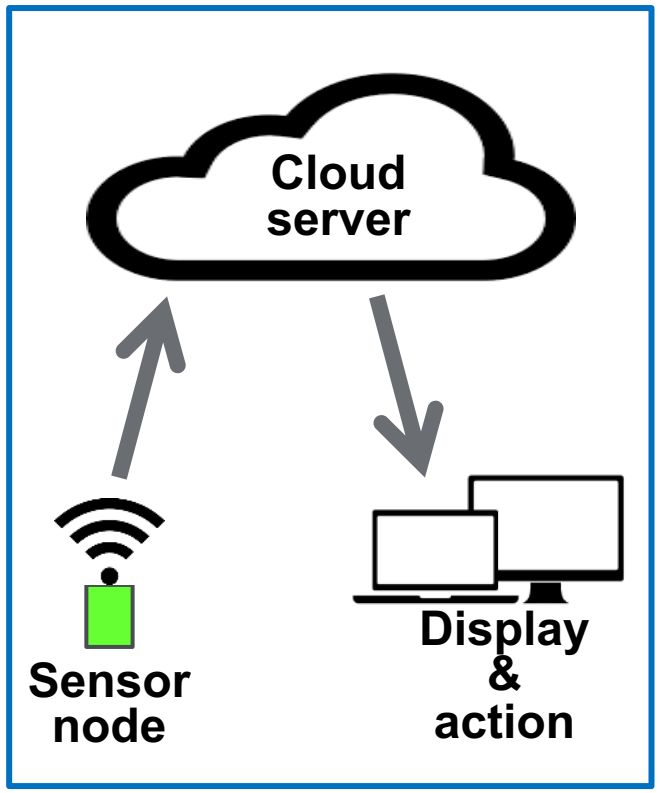


Potyrailo, *Chem. Rev.* **2016**

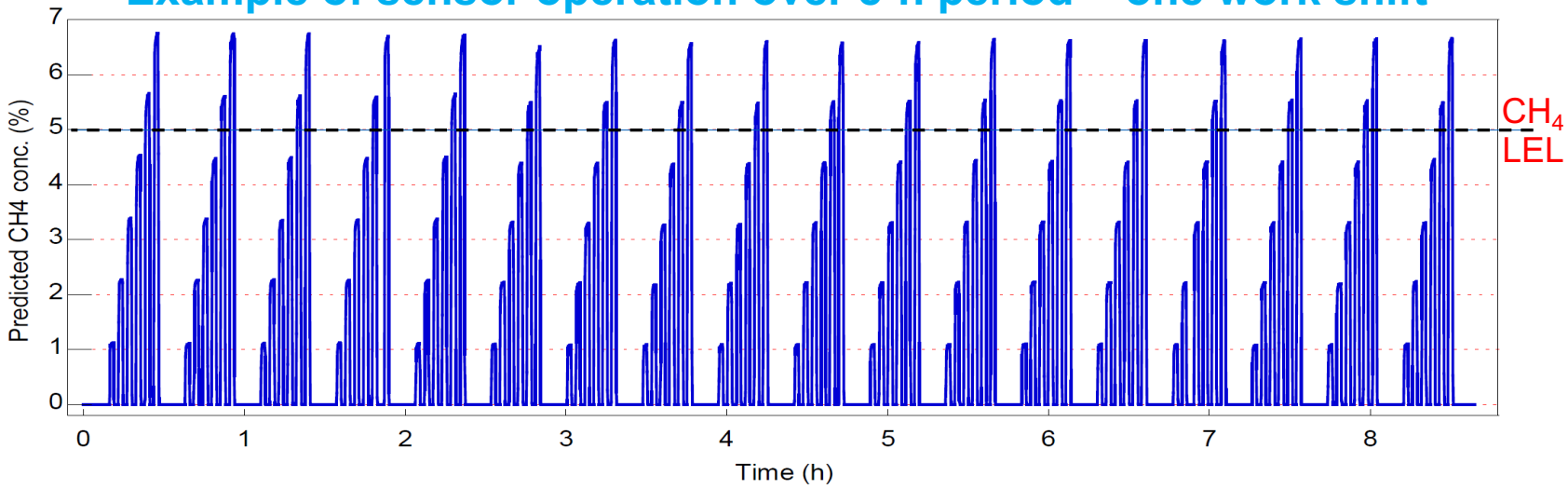
Exploring fundamental capabilities of multivariable RF and RFID sensors for diverse applications

All Photos by R. A. Potyrailo

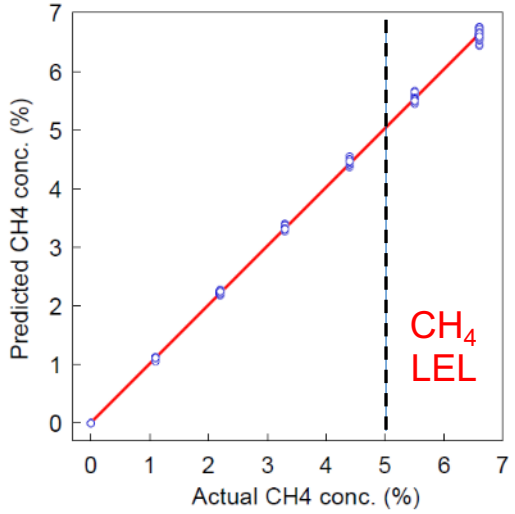
Gas sensors for occupational safety: CH_4

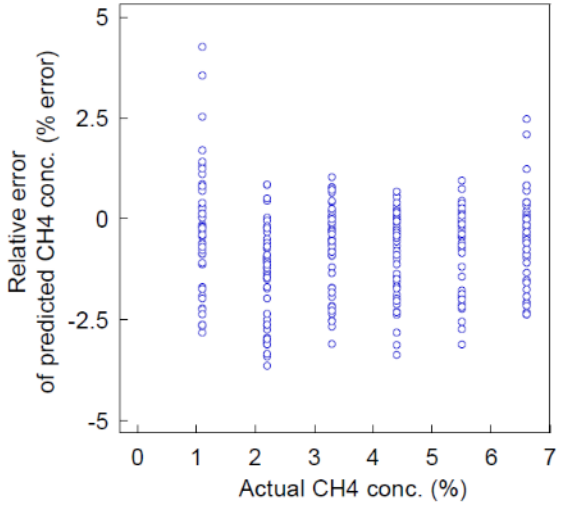


Example of sensor operation over 8-h period = one work shift



Statistics of sensor performance





LEL = low explosive limit

Robots for Dangerous and Repetitive Tasks

Factory and Field Deployment of Robots and Drones

- Deploying a companion robot with a human worker
- Augmenting the worker with an exoskeleton
- Utilizing robots and drones for inspection of factories

Approach depends upon hazardous the task is and how you need the human brain involved in the process.

https://www.suitx.com/

imagination at work

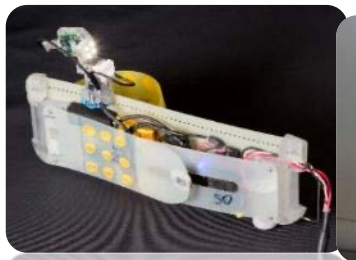
Soft robotics for manufacturing and industrial services

- **Unique capabilities of soft robots** for delicate manipulation, environmental compliance, confined navigation, variable stiffness, reconfigurability and self healing.
- **Transformational productivity improvements possible for industrial services:**
  - On-wing maintenance & repair for the $80 billion Aviation MRO industry.
  - In-situ repairs for large industrial assets, reducing outage duration & cost
  - Automated handling of delicate products for agriculture and e-commerce order fulfillment ($5 trillion industry by 2021.)
  - Active exosuits for human capacity augmentation on the shop floor.
- **Major advancements will be needed to make fabrication of soft robots accessible, reliable and scalable.**

GE application examples

Aircraft Engine Coating Restoration Soft Robot

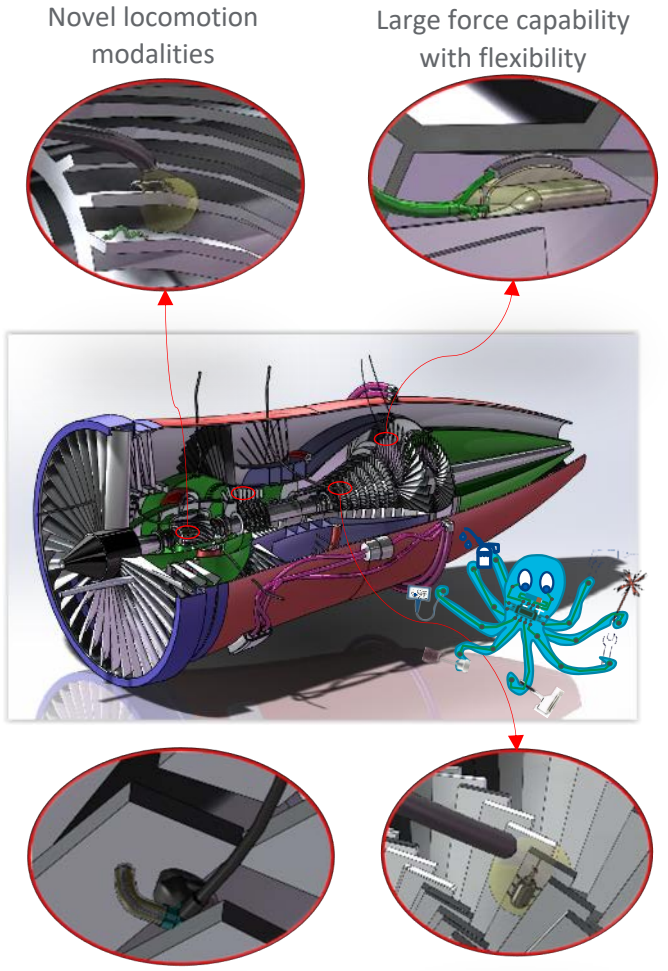
Aircraft Engine Shroud Inspection and Spray Device



Gas Turbine Hot Gas Path Inspection Flexible Robot

Flexible Snake Robots for Inspection and Repair

Future concepts - MRO example



* Flexible sensors for strain, temperature, radiation, force, cracks, chemical concentration, contact, etc. Flexible batteries, microcontrollers and interconnects. Flexible actuators for movement, heat, light and sound.

Adoption of Industrial Digital Technologies in Manufacturing

- Faster more predictable cycle times
- Higher quality
- Lower cost

FHE Technologies well suited for

- Tracking
- “cradle to grave” sensing of asset
- Single use sensors
- Wearable technology for digital assist, hazard identification, biometric assessment
- Robotic assist to augment human capabilities
- Soft Robotics for service, repair, inspection, remanufacturing
- Light weight sensors on inspection robots