Nuclear Plant Modernization and the Application of Wireless Sensors and Additive Manufacturing

Passive Wireless Sensor Technology (PWST)
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EPRI's History…Born in a Blackout

EPRI was founded in 1972 following The Great Northeast Blackout in New York City in 1965

Nonprofit

Chartered to serve the public benefit

Independent

Objective, scientifically-based results address reliability, efficiency, affordability, health, safety, and the environment

Collaborative

Bring together scientists, engineers, academic researchers, and industry experts

Are we in danger of losing the operating nuclear fleet?

- Recent plant closures primarily economic
  1. Low electric load growth
  2. Growing renewables
  3. Cheap natural gas
- Proposals to increase revenue of nuclear electricity
  - Carbon-free, grid stability
- But, inexpensive electricity is good!

What if instead, reduce the costs to operate?

- Nuclear plants have relatively high operating costs
- Nuclear fuel relatively inexpensive
- What if we reduce the non-fuel costs?
- What's that worth?

How to reduce costs?

- Same way non-nuclear generation, oil / gas, process chemical, aerospace, etc. have
- Process improvement & digital technology!

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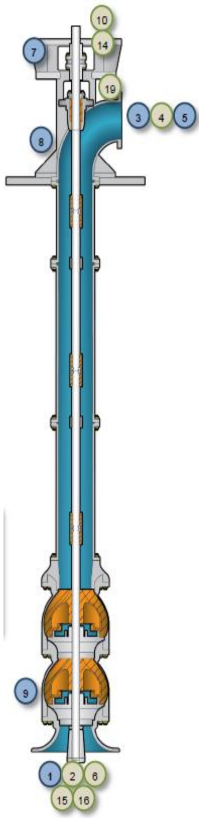
Process improvement + digital technology = Savings

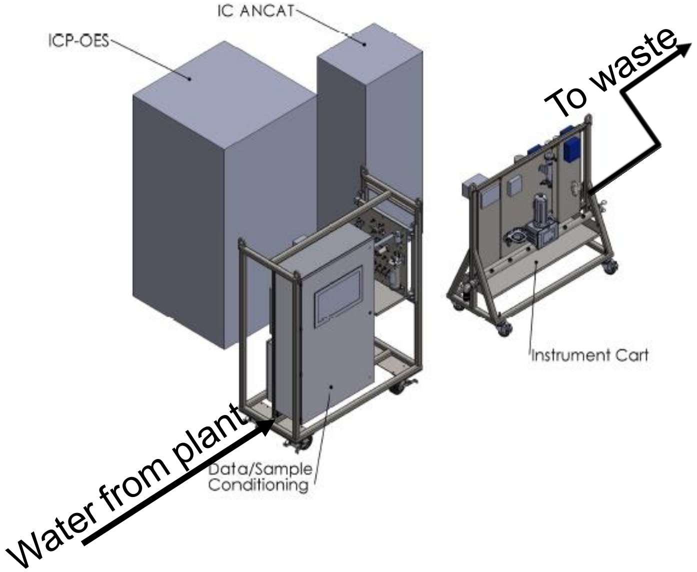
Sensor installation & simple data analytics can reduce manual maintenance tasks
“Quick Guides” pilot: savings potential 25,000 USD per pump-motor per year



From “QUICK GUIDE Continuous On-Line Monitoring (COLM): Vertical Pump, 3002012763

Ultrasonic transmitters to monitor for air voids, welds, other structural health applications

Prototype installed in EPRI Monitoring, Automation & Data Lab – communicating through our Distributed Antenna System (DAS) to a location several miles away.

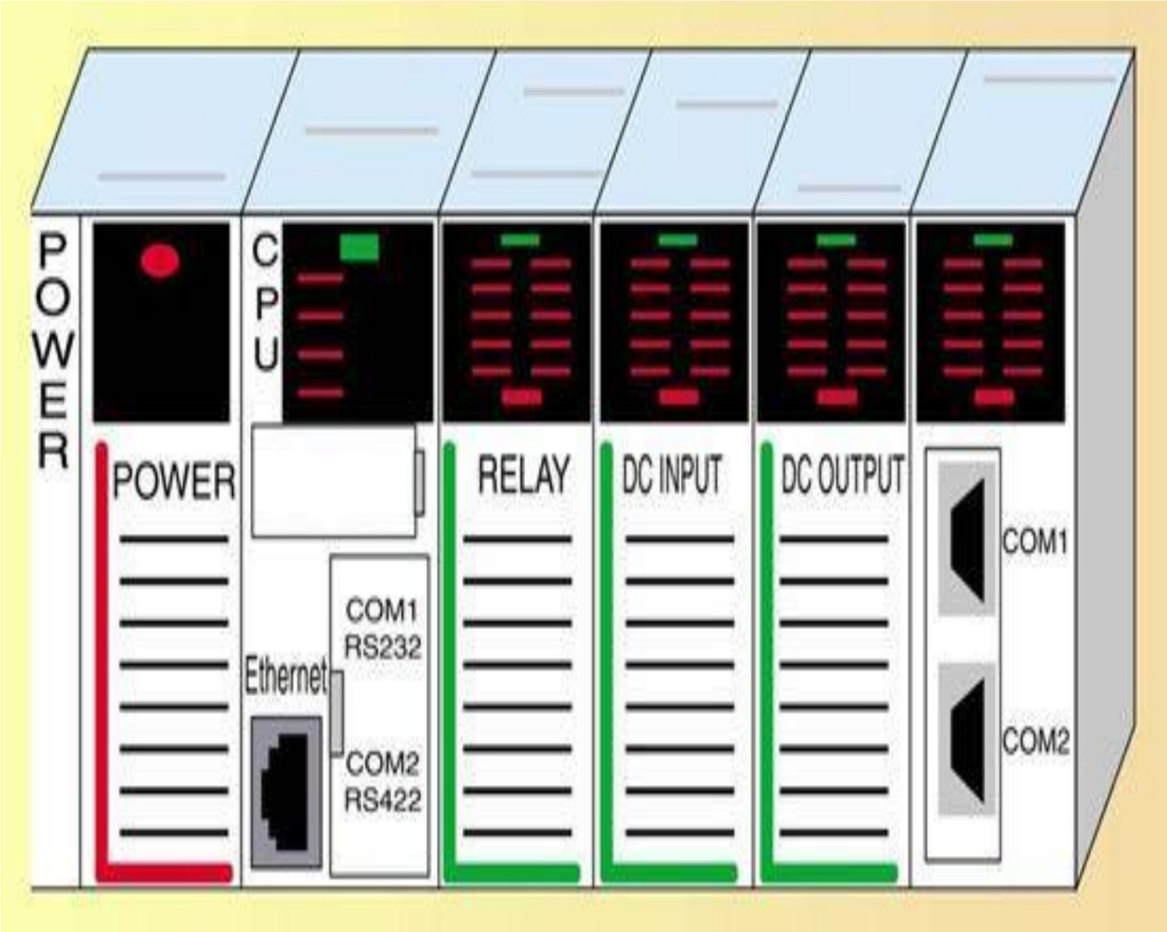


Automated chemistry sampling & data gathering
Reduce chemist labor to sample and analyze

Modern digital technology needed at scale

- Sensors
- Digital controllers
- Pervasive wireless (and wired) connectivity
- Computer processing data & recommending actions

- Integrating the plant with technology requires an integrated approach
  - Digital Engineering Guide (EPRI Report 3002011816, Published November 2018)



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PLANT MODERNIZATION

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Industry

Vision

Preserve nuclear power as a carbon-free, safe, and reliable energy resource.

Mission

Achieve nuclear power plant economic viability through transformative technology and innovation to optimize operations & maintenance while ensuring safety and reliability.

Collaborators

» Utilities
» EPRI
» U.S. Department of Energy (DOE)
» Owners Groups, Vendors, other R&D organizations
» Nuclear Energy Institute (NEI)
» Institute of Nuclear Power Operations
» WANO, IAEA, NEA

Strategic Goals

Feasibility
Show that modernization effort can be successful

Methods
Build confidence to make decisions to modernize

Approval
Demonstrate modernization can be implemented

Technology Enablers

Electronic Work Packages | Condition Based Maintenance | Risk-Informed Engineering | Digital Upgrades | Wireless Connectivity | Automated Chemistry Monitoring | Big Data Analytics | Automated Radiation Monitoring | Security | Drones | Structural Health Monitoring | CIM Common Information Model

PHASE I
Feasibility

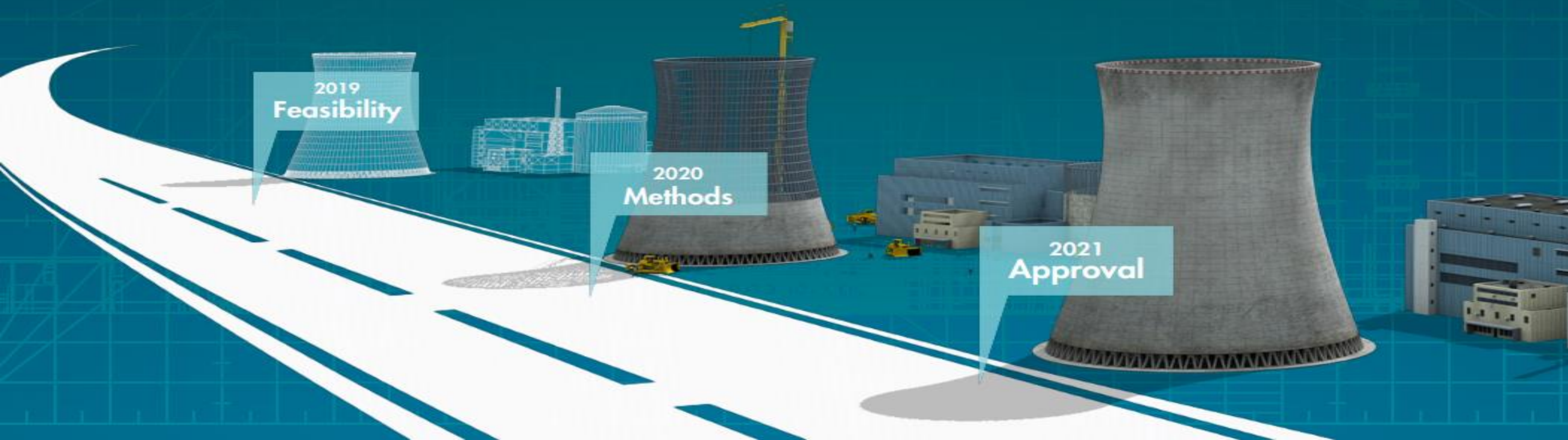
- End-state vision
- Basic economic return-on-investment
- Existing enabling technologies
- Research of new technologies
- Regulatory planning
- Demonstrate cost savings
- **Product: Business case**

PHASE II
Methods

- Deployment methods
- Technology research continues
- Regulatory solution
- Candidate plants
- **Product: Plant modernization handbook**

PHASE III
Approval

- Technology business case
- Full modernization conceptual design
- Implementation business case
- **Final Product: Plant modernization handbook with case studies**

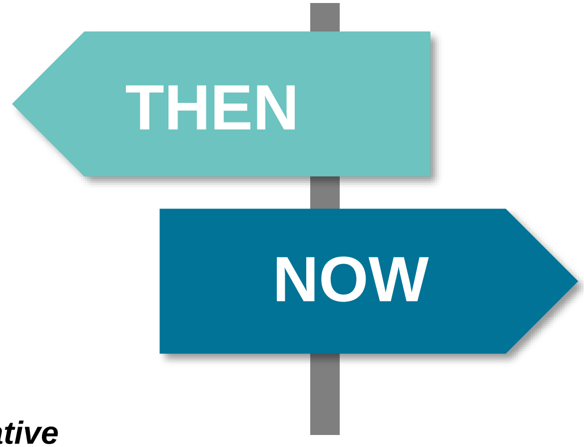


New Era – New Focus on Plant Operation

“Monitoring – Same Term, New Approach”

<u>Pre-DNP plant monitoring approach</u>

- Focus on **safety** related equipment
- Permanently mounted, **wired** sensors
- Data parameters feed into **operation domain**
- Advanced Pattern Recognition (APR) models built for establishing trending/alert levels
- Centralized monitoring centers



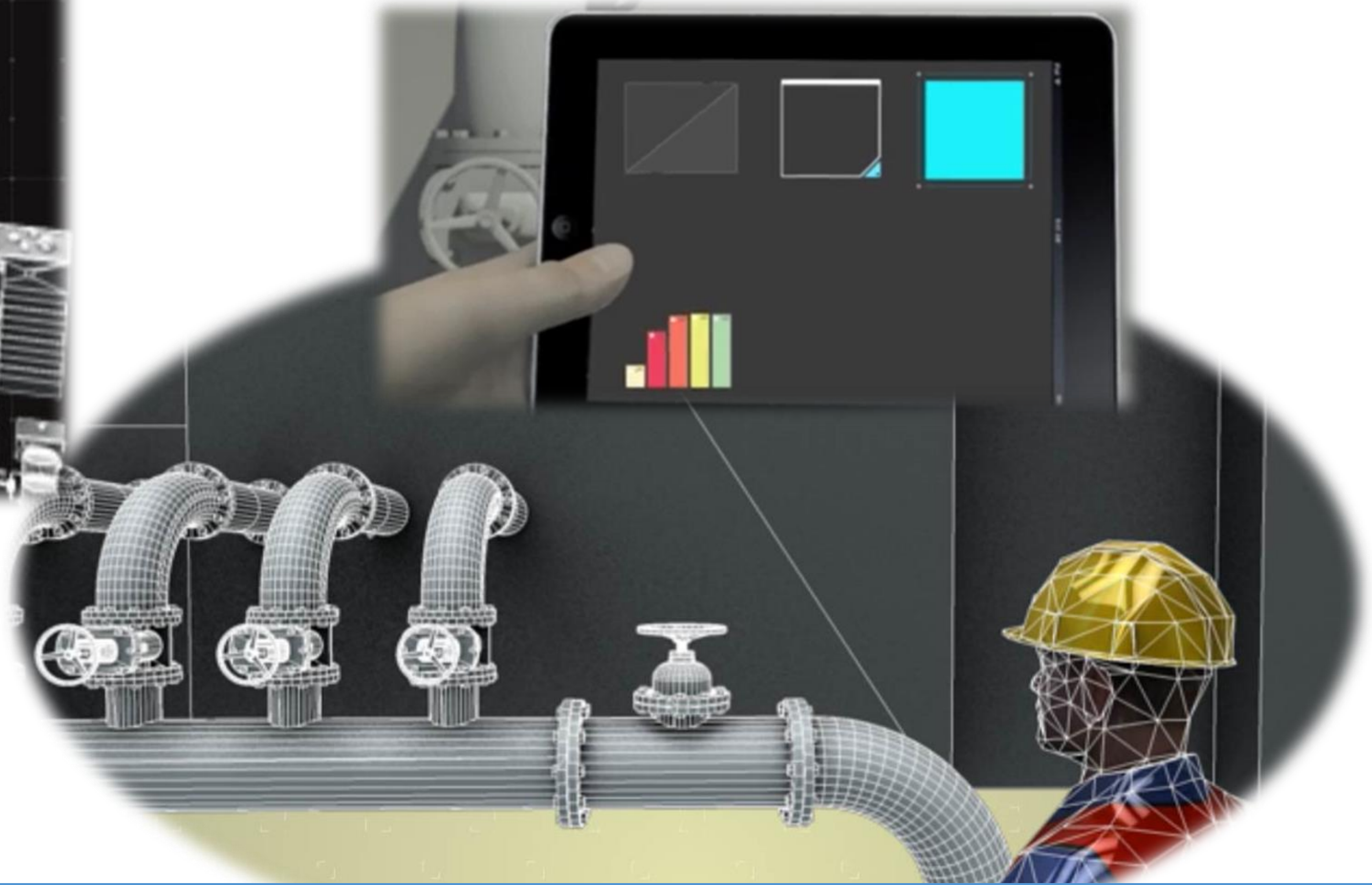
<u>DNP plant monitoring approach</u>

- Focus on components important to **production**
  - Forced loss rate minimized
  - Megawatt losses minimized
- Buildout of **wireless** infrastructure
- Continuous to near-continuous monitoring for Maintenance, Monitoring and Diagnostics **(MM&D) domain**
  - Wired and wireless solutions
- ***Reduce PM tasks** through Automation*
- ***Optimized maintenance frequencies** with increased data collection*
- Centralized monitoring centers (for fleets)

DNP – Delivering the Nuclear Promise initiative

Where the Industry is Going

Digital
Worker



Remote Online
Monitoring

Ability to move large amounts of data

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Current Industry Wireless Status

Who has a wireless network installed?

- 1st define the boundary
  - Office areas and shops – most have
  - Turbine building – majority have
  - Rx and Aux building – very few
- Holistically very few have enough coverage to support moderate plant monitoring needs
- Those who don’t have, want it. Others have it planned.
- Everyone is trying to figure out the best solution

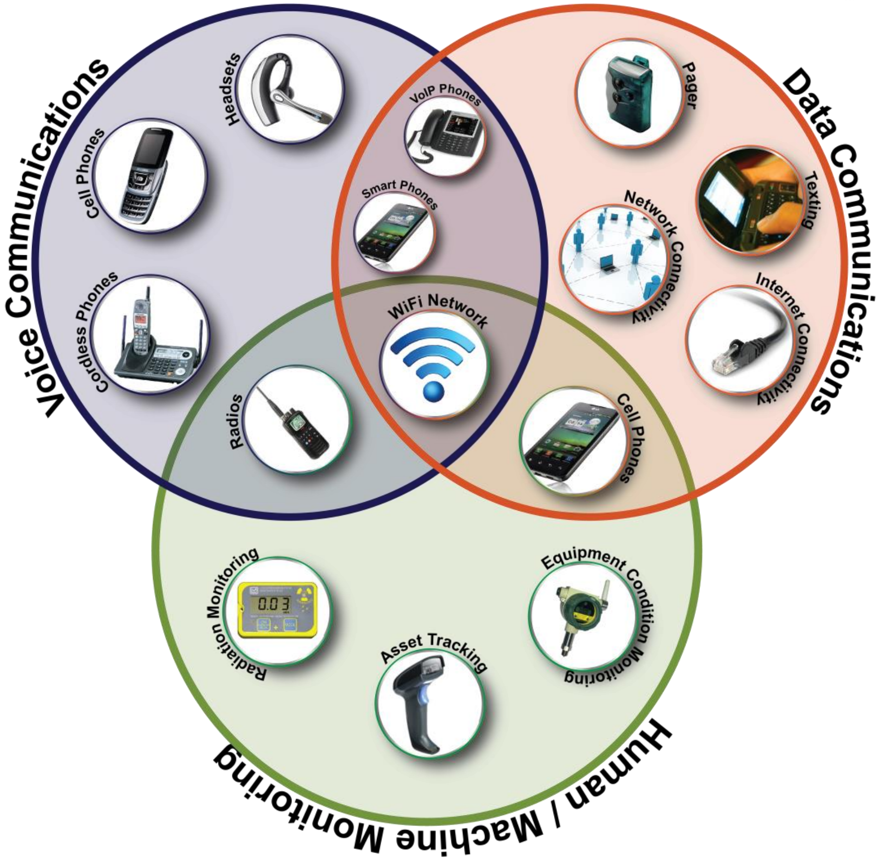
IT Infrastructure Challenges

- Capacity
  - More applications = more users = more data
- Continuously emerging technologies
  - Latest today, outdated tomorrow
- Budget constraints
  - Support resources
  - Hardware upgrades

Overcome the Challenges with Forward Motion

Wireless Sensors: Where are we today?

- Limited use by the industry
  - Great potential
  - Growing utilization
  - Some technology available
  - Clear benefits
- **Benefits**
  - Optimize Maintenance Activities
  - Reduce O&M Costs through Equipment Condition Monitoring
  - Save Manpower
  - Streamline Equipment Repair or Replacement Schedules



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Sensors in Nuclear Power Plants

- Many different types of sensors are within nuclear power plants
- Most of those sensors have many similar components
- Must operate reliably within power plant environment

Anatomy Sensing Equipment

Battery / Power Conditioning	Wireless Transmission
	Microcontroller
	Measurement Electronics
	Transducer

Temperature

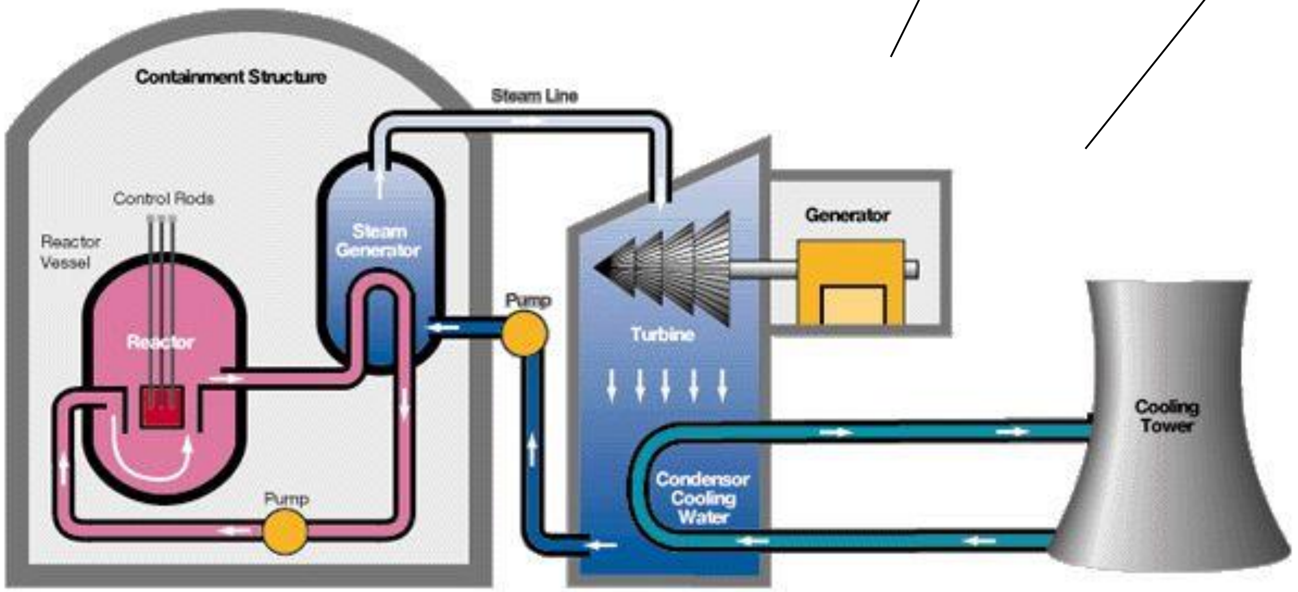
Current/Voltage

Chemical Species

Vibration

Coolant Chemistry

ETC



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The Keys to Success…

- Seamless integration with plant systems
- Low power consumption (i.e., low maintenance)
- Network reliability
- Network coverage
- Managed Challenges
  - Cyber Security
  - EMC

http://www.sensorsmag.com/networking-communications/wireless-sensor/wireless-sensor-use-is-expanding-industrial-applications-7212

Minimize Battery Maintenance

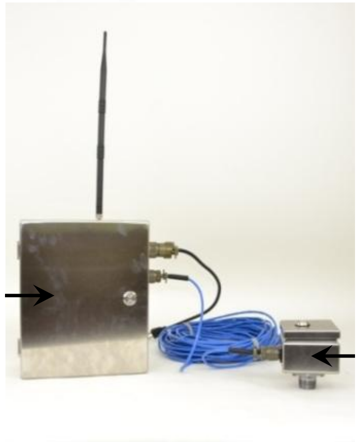
- **Chemistry**
  - Lithium Ion Based
  - Alkaline
- **Package**
  - Internal
  - External
  - Disposable
- **Environmental effects**
  - Battery Life
  - Shelf Life
  - Current Draw
- **Power Harvesting**

Installation Considerations

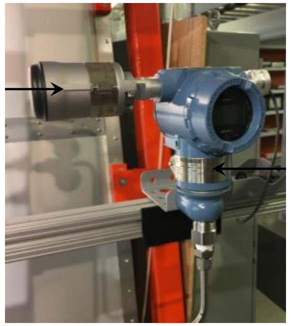
- **Sensor Mounting**
  - Magnetic
  - Permanent
  - Wire Strap
- **Coverage**
  - Sensor Placement
  - Mapping/Measurements
  - Antenna Pattern, Orientation, and Gain
- **Cabling Requirements**
  - Routing
  - Conduit/Cable Tray
  - Cable Type
- **Plant Documentation**
  - Engineering Work Package
  - Fire Load Calculations
- **Battery Considerations**
  - Type
  - Replacement Cycle
- **Electromagnetic Compatibility**
  - Emissions & Susceptibility
  - Best Practice and Risk Mitigation
  - Exclusion Zone (if any)

Sensor Technologies in Use

- Standalone Sensor/Transmitter
  - Advantages – self-contained, ease of implementation
  - Disadvantages – battery life, signal strength



- Wired Sensor with Wireless Hub
  - Advantages – sensor availability, optimal Tx placement, protocol selection
  - Disadvantages – requires cable installation (signal and possibly power), increases engineering costs



- Wireless Adapter
  - Advantages – integration with existing sensors
  - Disadvantages – requires compatible plant instrumentation, intrusive

Sensor Gaps and Challenges

- **Limited Selection of Technologies**
  - Few Industrial Grade Wireless Sensors
    - Majority are process sensors with some vibration sensors
  - Should be able to address the “low-hanging fruit” condition monitoring applications
  - Capabilities vary with limited options within each frequency band and protocol
    - Segmented vs non-segmented frequency bands, etc.
- **Wireless Hub versus Numerous Standalone Wireless Sensors**
- **Size and Cost**
- **Extended Battery Life and Power Harvesting Capabilities**
- **Environmental Conditions**
  - Industrial Grade
  - Radiation Hardened

Example - Selecting a Sensor

General System Considerations

- **Application**
  - Wireless vibration monitoring of containment cooling fans and control element drive mechanism (CEDM) cooling fans
  - Two sensors (radial and axial) at each fan location
  - Collect overall trend, spectrum and waveform once daily
- **Cannot interact with the system during the 18 month operating cycle**
- **Make data available to the PdM Engineers**
- **Use existing wires to pass communications through containment**

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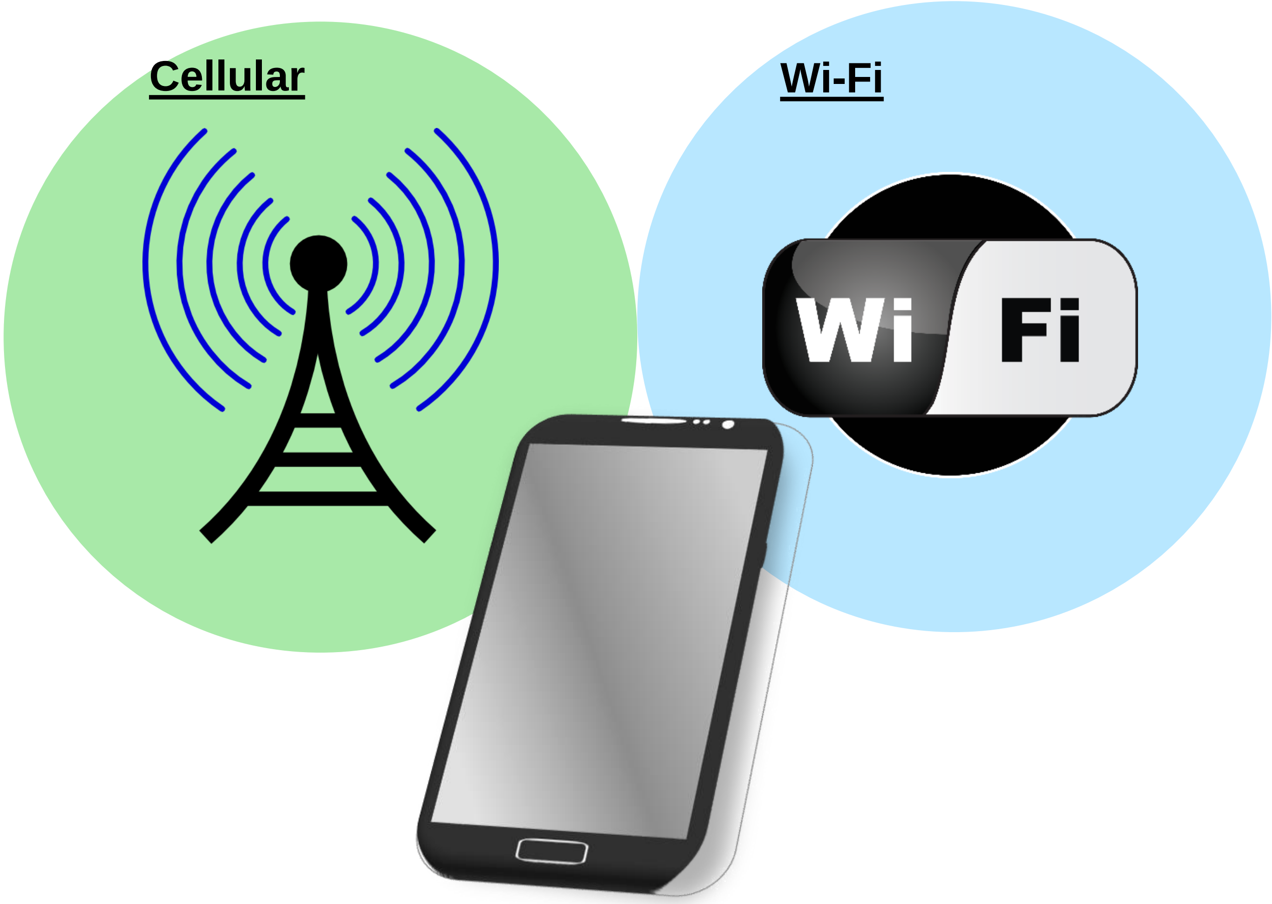
Example Wireless Sensor Requirements

Requirements	Description
Fire Load	System must not add appreciable combustible material to containment
Secure Anchoring	System must be anchored such that it will not dislodge and be swept into the sump system.
Ambient Environment	System must survive at 95°F, relatively low humidity, and low levels of radiation (e.g., <1 mrem/hr)
EMI/RFI	System must not interfere with existing equipment, nor be impacted by the target environment. Communication frequency must be 2.4 GHz.
Cyber Security	System must incorporate Wi-Fi Protected Access II (WPA2) security features

What passive wireless sensor solutions are available?



Added Complexity with Sensors

- Communication protocol
- Transmission power
- Range
- Sensor Power

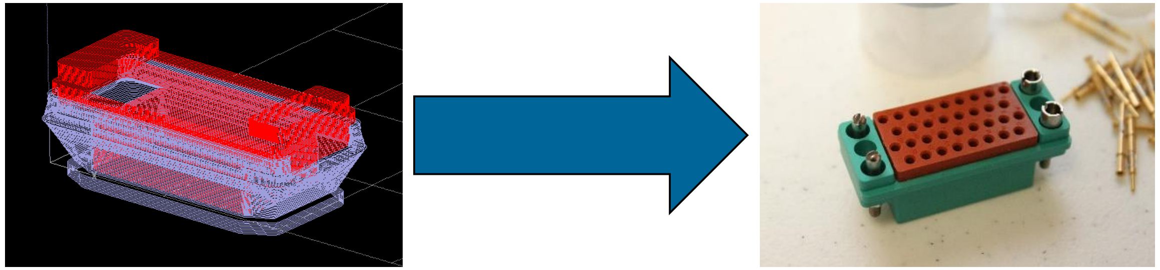
Smart (Advanced) Manufacturing

- Advanced manufacturing and digital technologies combined to produce customized products faster, more accurately, and less expensively
- Powder Metallurgy Hot Isostatic Processing (PMHIP)
- Additive Manufacturing with Metals (3D) / ASTM F42 Committee
  - Powder bed (laser, fusion, electron beam melting)
  - Sheet lamination
  - Directed energy deposition
  - Binder jetting

Smart (Advanced) Manufacturing (cont.)

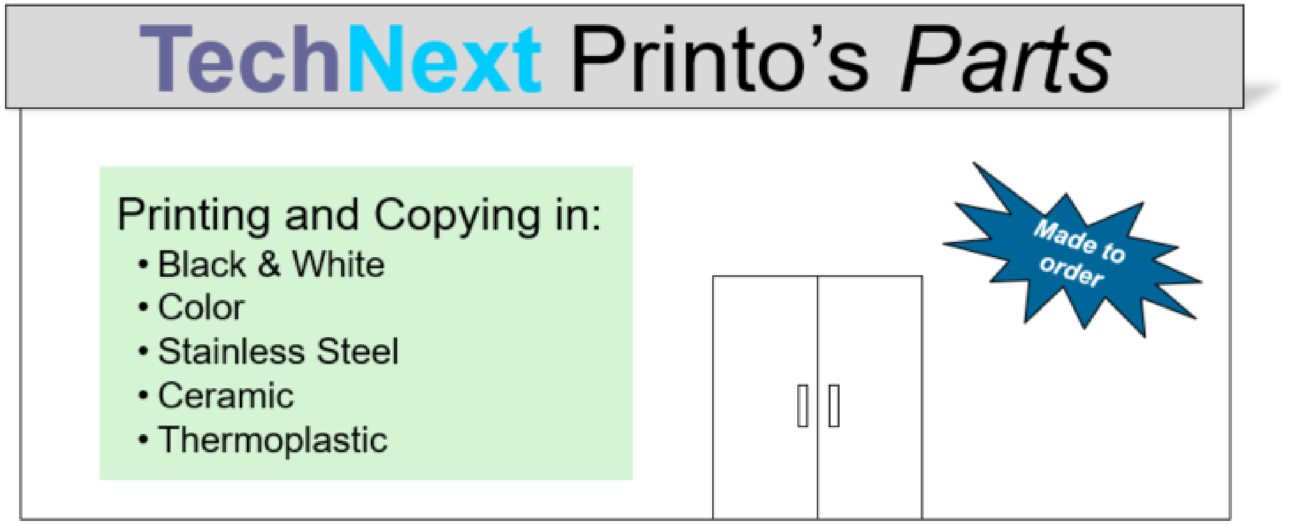
- Additive manufacturing with thermoplastics
  - Stereolithography (SLA) Laser polymerizes a resin
  - Selective Laser Sintering (SLS) – Laser selectively fuses materials in a granular bed
  - Fused Deposition Modeling (FDM) – Polymer is heated and extruded through a nozzle

- Instead of building *"to meet"* a design, smart manufacturing technologies can build *"from"* a design



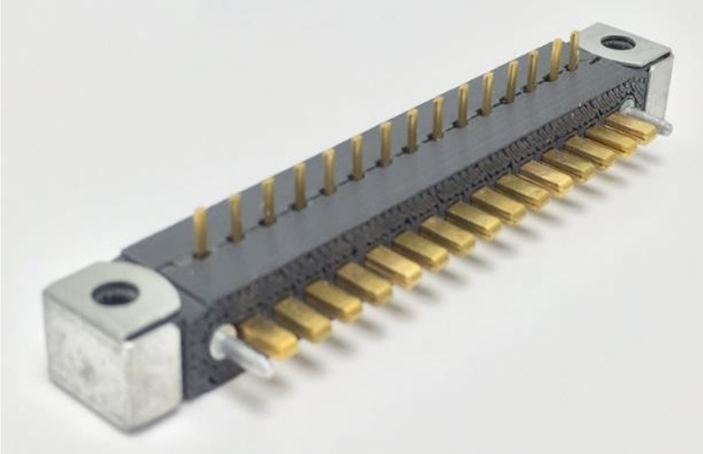
Additive Manufacturing Supply Chain

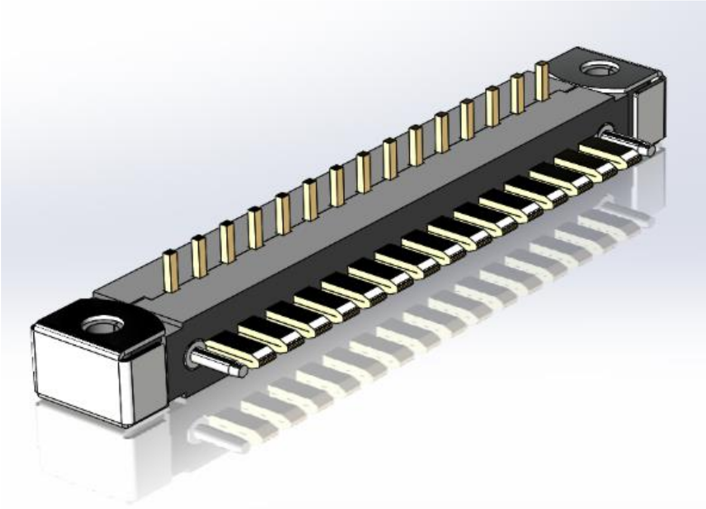
- Spares may not be manufactured concurrent with original product
  - No need to keep replacements in inventory
  - Aging and obsolete design information are made available for customer use



- "Replacement Item Centers"
  - Access available OEM "files"
  - Prototype, copy, and print replacement items

Additive Manufacturing Supply Chain





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