SEMI Public Private Partnerships: Wearables Case Study

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R&D Program Manager, SEMI-FlexTech and Nano Bio Materials Consortium
Contents

- Wearables as a market
  - Historical and Contemporary Timeline
  - Form factors
  - Case study: Fitness trackers

- Wearables as part of IoT

- Existing Supply Chain (and some self promotion)

- Public Private Partnership for Flexible Electronics & Wearables
How do we define “wearable”?
What is a wearable?

An electronic device to augment human senses or capabilities worn on an individual

Pre-electronic wearables

1770 - Self winding watch mechanism
1780 - Pedometer (Perrelet)

1880s Electrodermal Activity (Fere, Tarchenoff)
  - 1903 EKG (Einthoven)
  - 1921 Skin conductance response (aka GSR (polygraph))

1888 - Electric Hearing Aid (Hutchison)

1923 – Pedometer patent
1938 – Wearable Hearing Aid

1965 – Commercial pedometer Manpo-Kei (Hatano)
No major changes in form factors since early commercialization

Wrist based

1915

2018

Ear based

1938

2018

Why?

• Human form factors have not changed.
• Silicon microelectronics are rectilinear, like most pre-electronic mechanisms
• Fashion designers and electronics designers are now beginning to collaborate
• Soft/hard material termination, flexible component miniaturization, device reliability, cost
Case Study: Fitness Trackers (1 of 2)

• Began as AliphCom military audio technology
• Market timing success with the Bluetooth headset
• Led Bluetooth audio players
• Initial wearable success with Jawbone Up fitness tracker
• $950 Million (USD) in Venture Capital Funding with $3.2Billion USD valuation
• Differentiator: Design

• Inspired by the Nintendo Wii
• Multiple generations of products
• Market timing success after Jawbone recall
• Went public June 2015; maximum market capitalization > $11 Billion (USD) now 1.2B USD
• Lost market leadership position to Xiaomi
• Differentiator: Socialization
Case Study: Fitness Trackers (2 of 2)

Winners: Smart Watches, Sports watch, Band Trackers

• Smart Watch: Apple (iOS), Samsung (Android)
  – Established Ecosystems
  – Phone integration
  – Brand awareness
  – Quality and reliability

• Sport Watch: Garmin
  – Well defined user base (athletes)
  – GPS integration
  – Longer product life cycles
  – Long battery life
  – Open ecosystem

• Garmin band
  – Long battery life
  – Reliability
  – Low cost Garmin option

• Xiaomi
  – Large feature set at 20% of other tracker costs
  – Large display
  – Band options
Technology Evolution Needed

Technology evolution in wearables has been incremental

- Miniaturization
- Double sided boards
- Incorporation of some printed electronics
- In mold electronics

Why?
- Market timing
- Manufacturing retooling constraints; high volume wearables are manufactured like cell phones.

Opportunities
- Form Factors
  - Patches
    - Consumer familiarity
    - **No electronic interface required**
  - Textiles
    - Existing automation
    - **Soft/Hard material termination tools need scale-up**
- Power
  - Extreme low power devices
  - **Sensing/communicating on demand**
  - Energy harvesting
Wearables, Revisited
IoT
Technology Hype Cycles
Wearables are things (IoT)

**Gartner IoT definition**

“Dedicated physical objects that contain embedded technology to sense or interact with their internal state or external environment”

“IoT comprises an ecosystem that includes devices (things), communication, middleware, applications, and data analysis.”

- 20.4 billion devices by 2020
- Business applications well defined
- Consumer lagging
- 33% CAGR through 2020

*Source: Forecast: Internet of Things -- Endpoints and Associated Services, Worldwide, 2016, G00321441*
Wearables are a subset of IoT devices

Observations

• Semiconductors dominate IoT devices
• Flexible electronics CAGR estimates range widely; the average is roughly 13%.
• Health/wellness leads growth for flexible electronics
Gartner Hype Cycle

- **On the Rise**
  - Supplier proliferation
  - Mass media hype begins
  - Early adopters investigate
  - First-generation products, high price, lots of customization needed
  - Startup companies first round of venture capital funding
  - R&D

- **At the Peak**
  - Activity beyond early adopters
  - Negative press begins
  - Supplier consolidation and failures
  - Second/third rounds of venture capital funding

- **Sliding Into the Trough**
  - Less than 5 percent of the potential audience has adopted fully

- **Climbing the Slope**
  - Methodologies and best practices developing
  - Second-generation products, some services

- **Entering the Plateau**
  - High-growth adoption phase starts: 20% to 30% of the potential audience has adopted the innovation
  - Third-generation products, out of the box, product suites

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**Technology Trigger**
**Peak of Inflated Expectations**
**Trough of Disillusionment**
**Slope of Enlightenment**
**Plateau of Productivity**
Gartner Hype Cycle For Emerging Technologies, 2015

- **Innovation Trigger:**
  - BCI
  - Quantum
- **Peak of Inflated Expectations**
  - Autonomous Vehicles
  - Internet of Things
- **Trough of Disillusionment**
  - Augment Reality
  - Cryptocurrency Exchange
- **Slope of Enlightenment**
  - Gesture Control
  - Enterprise 3D Printing
Gartner Hype Cycle For Emerging Technologies, 2018

- Innovation Trigger:
  - Blockchain for data security
  - Neuromorphic hardware
- Peak of Inflated Expectations
  - Deep Learning
  - Carbon Nanotubes
- Trough of Disillusionment
  - Connected Home
  - Mixed Reality
## Wearables in the Hype Cycle

*Data taken from Gartner, 2018*  
*Bolding by speaker*

<table>
<thead>
<tr>
<th>On The Rise</th>
<th>At the Peak</th>
<th>Sliding into Trough</th>
<th>Climbing Slope</th>
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<tbody>
<tr>
<td>Skin Bio Patch</td>
<td>Mobile EKG devices</td>
<td>Biometric Earbuds</td>
<td>Connected Personal Hearing Devices</td>
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<tr>
<td>Exoskeleton</td>
<td>Electromyography wearables</td>
<td>Head Mounted Displays</td>
<td>Positive Patient Identification</td>
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<td>Galvanic Skin Response</td>
<td>Wearable UV monitors</td>
<td>Smart Watches</td>
<td>Wristbands</td>
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<td>Head Mounted EEG</td>
<td>Smart garments</td>
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<td>Personal Trackers</td>
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<td><strong>Smart Footwear</strong></td>
<td>Wearable Speech Based Controller</td>
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<td>Sports Watches</td>
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<td><strong>Noninvasive glucose monitors</strong></td>
<td>Gesture control devices</td>
<td></td>
<td>Mobile Personal Emergency Response Systems</td>
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<tr>
<td>Smart Badges</td>
<td>Wearable blood pressure monitors</td>
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</table>

**Coming out of R&D**  
**Utilizes existing tech**  
**Adopted**
CES 2019: A Small Selection of Exhibited Wearables

- Withings Move ECG
- Willow 2 Breast Pump
- nreal mixed reality glasses
- spherio specdrums
- Exosystems exoRehab
- La Roche Posay My Skin Track pH
A Second to Last Look at Gartner Trends

Possible plays *if* FHE/PE/MEMS/Sensor communities are proactive

- **Biohacking**
  - Exoskeletons
  - Smart Fabrics
- **Immersive experiences**
  - Smart Dust
  - Silicon Anode Batteries
- **Ubiquitous Infrastructure**
  - Carbon Nanotubes
  - Quantum Computing

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Additional information:

**Democratized AI**
- AI PaaS
- Artificial general intelligence
- Autonomous driving Level 4
- Autonomous driving Level 5
- Autonomous mobile robots
- Conversational AI platforms
- Deep neural nets
- Flying autonomous vehicles
- Smart robots
- Virtual assistants

**Digitalized Ecosystems**
- Blockchain
- Blockchain for data security
- Digital twin
- IoT platform
- Knowledge graphs

**Do-It-Yourself Biohacking**
- Biodevices
- Biotech—cultured or artificial tissues
- Brain-computer interface
- Exoskeletons
- Augmented reality
- Mixed reality
- Smart clothes

**Transparency Immersive Experiences**
- 4D printing
- Connected home
- Edge AI
- Self-healing system technology
- Silicon anode batteries
- Smart dust
- Smart workspace
- Volumetric displays

**Ubiquitous Infrastructure**
- 5G
- Carbon nanotubes
- Deep neural network ASICs
- Neuromorphic hardware
- Quantum computing
A Final Look at Gartner Trends: Top 10 Technology Trends for 2019

- Areas of Interest to the Electronics Supply Chain
  - Quantum Computing:
    - Materials
    - Equipment (cryogenics)
    - Photonics
  - Digital twin, Smart spaces:
    - Communication
    - Components

- Not shown: Security
  - Part of Privacy?
  - Security solutions will be multi-layered: hardware, software, traceability, verification
Question: Does the market support wearables? (no killer products, not in the hype cycle)

Let’s look at the greater electronic supply chain and application verticals.
Without this.

None of these.
SEMI Connects the Electronics Manufacturing Supply Chain

SEMI global platforms, standards, technology communities, interest groups, committees, conferences, and expositions gather the extended electronics supply chain for comprehension, synchronization, and action.

CONNECT ♦ COLLABORATE ♦ INNOVATE
Five SEMI Vertical Application Markets

<table>
<thead>
<tr>
<th>“Consumer”</th>
<th>“Factory”</th>
<th>“Car”</th>
<th>“Health”</th>
<th>“Data”</th>
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<td>Home-related examples</td>
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<tr>
<td>• Wearables</td>
<td>• IIoT</td>
<td>• Safety</td>
<td>• Wireless patient monitoring</td>
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<td>• Smart Lights</td>
<td>• Industry 4.0</td>
<td>• Telemetrics</td>
<td>• Dose monitoring</td>
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<tr>
<td>• Smart Locks</td>
<td>• Machine Learning</td>
<td>• Infotainment</td>
<td>• Health and wellness monitoring</td>
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<tr>
<td>• Smart Thermostat</td>
<td>• Sensors</td>
<td>• Wearables</td>
<td>• Biometrics, sensing, and diagnostics</td>
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<tr>
<td>• Smart Coffee Pot</td>
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<td>• Car-to-car, car-to-road</td>
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<tr>
<td>• Smart Pet Feeder</td>
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<td>• Driverless cars</td>
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<td>Examples</td>
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<td></td>
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<td></td>
<td>• Secure data sharing</td>
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<td>• Analytics</td>
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<td>• AI/ML/Big Data</td>
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<td>• Cybersecurity</td>
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<td>• Blockchain</td>
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</tbody>
</table>

Flexible hybrid electronics, printed electronics, MEMS/sensors, and electronic textiles – *commonly used in wearables* -- will all play a role in these vertical markets.
FHE Application Segment Leader: Transportation

**Autonomy**
- Sensors
- Advanced driver assist
- Driver monitoring
- Highway pilot to full automation (SAE level 4-5)

**Cockpit of the Future**
- Functionality meets interior design
- Driver and passenger monitoring
- Displays – curved, center stacked, head-up

**Connected**
- Infotainment apps
- Local travelers’ services
- Telematics for fleets, roadside assist, infotainment

**Safety & Security**
- 360° birds eye view
- Information-rich lighting
- Anti-theft

**Fuel & Power**
- Electric vehicles – batteries
- Energy harvesting windows / devices

**Monitoring Requirements**
- Stringent automotive reliability requirements
- Cost effective
- Volume manufacturing
- Safety-critical standardization
- Anti misuse & abuse
FHE Application Segment: Medical, Health and Wellness

**Cognitive Function**
- Military, consumer, industrial, and athletics
- High value assets, safety, performance

**Telemedicine**
- Vital sign and geriatric patient monitoring
- Reduced health care costs
- Continuous measurement capability

**Treatment Response**
- Reduce treatment cycle times
- Reduced costs
- Lower mortality rates

**Aeromedicine**
- Coordinated triage
- Continuous vital sign monitoring
- Variable / austere environment

**Performance Monitoring**
- Improved health and wellness
- Athletic performance enhancement

**Monitoring Requirements**
- Cost effective
- Unique accuracy & precision
- Low maintenance
- Automated analytics
The first three modules are generic to any sensor system.

Image courtesy of GE Healthcare, R. Potyrailo.
Revisit Wearables from Consumer to Medical
Wearables for Medical Applications

Vital signs
- Heart rate
- Blood pressure
- Respiration rate
- Body/skin temperature
- Blood oxygen saturation level

Diseases
- Sleep apnea
- Chronic obstructive pulmonary disease
- Diabetes mellitus
- Cardiovascular diseases
- Brain diseases
- Mosquito-born diseases
- Renal failure
- Skeletal system diseases
- Hearing loss

Physiological functions
- Neural (N)
- Respiratory (R)
- Circulatory (C)
- Metabolic (M)

Graphic: GE Research


Potyrailo, et al., 2019

Clothing-integrated
- Worn
  - mymotv.com

Textile World 2019

Implanted
- profusa.com

Nature Electronics 2018

Ingested
- Nature Biotechnology 2016

Skin-interfaced
- mc10inc.com
Wearable Sensor Start-Ups

Examples of startups

Clinical Efficiency
- AUGMEDIX
- TeleTracking
- fruit street
- AdhereTech
- Obaa
- simplifey
- PRISTINE
- awarepoint

Clinical-Grade Biometric Sensors
- QUANTITUS
- vitalconnect
- AMC10
- Senseonics
- Sotera
- iRhythm
- Proteus
- EarlySense
- SilentAlert
- EYENETRA

Consumer / Home Monitoring
- sano
- GlucoVista
- QARDIO
- WHOOP
- eira
- CHRONOTHERAPEUTICS
- BIOSERENITY
- SCANADU
- THALMICLABS
- ANGEL SENSOR
- Kinsa
- STORINGSENSE
- INFOBIOMIC

Infant Monitoring
- Sproutling
- mimo
- Owlet

Fitness Wearables
- sensoria
- LUMO
- om signal
- lark
- Jawbone
- Withings
- Misfit

Sleep Monitoring
- beddit
- NovaSom
- Q

Brain Sensors / Neurotechnology
- NeuroVigil
- Thync
- ybrain
- NeuroSky
- Halo

Several of these are already out of business!

FOCUS ON: Clinical Efficiency, Biometrics, Fitness, Neurotechnology, Consumer/Home Monitoring, Infant Monitoring, Sleep Monitoring

https://www.cbinsights.com/research/iot-healthcare-market-map-company-list/
Physiological sensors: future research directions

Outcomes:
- Usability of diverse sensors without expert knowledge
- Operation cheaper and safer than the standard of care
- Executing functions that cannot be performed by a physician
- Interpreting data for predictive healthcare

Transducers:
- Detection of trace levels in biomarkers in body fluids
- Hyphenation of transduction modalities for more accurate sensing, elimination of ambient noise
- Reduction / elimination of biofouling

System-level integration:
- Materials for electronics and encapsulation
- Skin-interfaced electronics / sensors
- High-performance sensors for single- and long-term use

Power:
- Power efficiency
- Unobtrusive form factors

Signal out:
- Data transfer range
- Real time sensing

Signal analytics:
- Passive / active noise suppression
- Calibration simplicity

Outcomes:

Packaging / system integration

2019 REVIEWS
- Foster et al., The Opportunity and Obstacles for Smartwatches and Wearable Sensors, IEEE Pulse 2019, 10, 22-25
- Hao et al., Flexible Electronics toward Wearable Sensing, Accounts of Chemical Research 2019, 52, 512-513
- Joshi et al., Wearable sensors to improve detection of patient deterioration, Expert Review of Medical Devices 2015, 16, 145-154
- Liu et al., Wearable and implantable Triboelectric Nanogenerators, Advanced Functional Materials 2015, 25, 1809320
- Ray et al., Soft, skin-interfaced wearable systems for sports science and analytics, Current Opinion in Biomedical Engineering 2019, 9, 47-56
- Sharma et al., Toward a new generation of smart skins, Nature Biotechnology 2019, 37, 182
- Steger et al., Ingestible electronics for diagnostics and therapy, Nature Reviews Materials 2019, 4, 83-90
- Yu et al., Biocompatible Sensors: Biocompatible Soft Fluidic"
Question 1: Does the market support wearables?
Answer 1: It’s complicated.

Question 2: How do we accelerate technology development?
Answer 2: Public-Private Partnerships
Public Private Partnership:
FlexTech and Nano Bio Materials Consortium
Building Industry Consortia: History of FlexTech

1993  Founded as US Display Consortium
  • R&D partnership between industry and US Government
  • 136 projects - $205M combined investment

2008  Re-Launched as FlexTech Alliance in 2008
  • 55 projects – $32M combined investment

  • 17 projects – $15M combined investment

2015  Launched Manufacturing Innovation Institute – Flexible Hybrid Electronics - NextFlex
  • $75M federal investment + $90M in industry cost share

2016  Became SEMI’s first Strategic Association Partner

2018  NBMC Re-Launched as Nano-Bio Materials Consortium
  • $7M federal investment

4 Consortia Formed
$400M+ of Federal Investment + Industry Match
Collaborative Development
The Consortium Model

R&D Consortia

Flexible Hybrid Electronics Supply Chain Development
- CMOS integration
- Power
- Radio & communications
- Sensing, warnings, wearable displays

Flexible, Wearable Human Performance Monitoring
- Human performance monitoring/augmentation
- Medical application
- Wearable devices & subsystems

Pilot Manufacturing Consortium

Flexible Hybrid Electronics Manufacturing
- Manufacturing platforms
- Process design rules & kits
- Cleanroom assembly & system integration

Industrial Partner Objectives & Market Drivers

Government & Commercial Strategy Alignment

US Government Mission

R&D Consortia

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Flexible Hybrid Electronics Manufacturing
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Our Technology Focus: Flexible Hybrid Electronics

- Sensing, A/D signal processing, wireless integrated circuit systems
- Merging printed electronics with high performance traditional semiconductors
- All within a light weight, conformal or flexible/stretch-able format
- Ideal for mobile and wearable applications that need freedom of motion and/or contact to curved surfaces
R&D Direction Setting & Execution

- Assemble investment partners and governing council
- Identify needs and challenges
- Assess the technology landscape (technical council)
- Issue a request for proposal
- Fund projects – typically at a 50% cost share

- Q2 2017
- Q4 2017
- Q2 2018
- Q1 2019
- Q2 2019

Power Initiative Example
- Thin Film Power Source
- Printed Battery Materials
- Flexible Printed Battery
- Imprint Energy
- Novacentrix

Blood, Sweat and Tears II
May 17-18, 2016, Dayton, Ohio

Workshop & Tour

NDMC

Flexible Printed Battery

Imprint Energy

Novacentrix

Thin Film Power Source
Flexible, Non-invasive Wearable for Dynamic Assessment of Hydration Status

NBMC Consortium Project 16-10: A Collaborative team of 7 industry and university members lead by GE developed

1. Ion Selective Electrodes – Na+ and K+ concentration in sweat
2. RF Impedance Patch – subcutaneous hydration tomography and spectroscopy

Program supported by:
Flexible High Performance ICs

CMOS wafer prep

Pick & Place

3D Additive Interconnection

Roll to Roll Manufacturing

Program supported by:

Ultra-thin CMOS Assembly & multi-layer flexible PCB
Thin Light Weight Renewable Power Sources

Packaged Battery Thickness (microns)

- Primary & rechargeable battery
  - Capacity 30-90 mAh
- Advanced Packaging 
  & Integration
- Printing 
  & Lamination

Energy Density (Wh/l)

- Self-recharging
  - Ultra-thin
  - Power Pack

Program supported by:

ITN Energy Systems Inc. | ENrG Inc. | Lucintech Inc.

Power Module Integration + Advanced Materials + Photovoltaics
Current Project: ITN, ENrG, Lucintech, University of Rhode Island

Figure 3. Schematic illustration of the integration of the proposed thinned, high performance silicon microelectronics on ultra-thin YSZ circuit board to enable a new MIPM and BIPASS products.
## Technology Landscape: Representative Programs

### MARKET DRIVERS

<table>
<thead>
<tr>
<th>Power</th>
<th>Ultra thin flexible integrated power pack</th>
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</thead>
<tbody>
<tr>
<td>Flexible PCB</td>
<td>Printed Interconnect &amp; Resistor, Flexible Ceramic</td>
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<tr>
<td>Sensors (1)</td>
<td>Non-Invasive Bio Fluid; Saliva, Sweat Sensors</td>
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<tr>
<td>Sensors (2)</td>
<td>Highly Flexible Audio Enabled Hybrid Smart Tags</td>
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<tr>
<td>Wireless</td>
<td>Self Powered Wearable Device for Dynamic Assessment of Hydration</td>
</tr>
<tr>
<td>IC Integration</td>
<td>FHE Direct Chip Attach</td>
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<tr>
<td>System</td>
<td>ECG Biomarker Microfluidics for Sweat Biomarker Sensors</td>
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<tr>
<td>HMI</td>
<td>Audio, Display, Capacitive Gel Contact Electrodes</td>
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<tr>
<td>Software</td>
<td>On Board SW (sense and signal conditioning), API, PC-Host User Interfaces</td>
</tr>
<tr>
<td>3D Printing</td>
<td>Conductive &amp; Dielectric 3D Equipment Development with in-situ Sintering</td>
</tr>
<tr>
<td>Machine Tooling</td>
<td>Implementing FHE Prototype and Production.</td>
</tr>
<tr>
<td>FHE Reliability</td>
<td>Bend Testing Criteria &amp; Evaluation, Environmental (high temp/humidity) Testing</td>
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</table>

### Technology Landscape Table

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**TRL** stands for **Technology Readiness Level** and **MRL** stands for **Market Readiness Level**.
# NBMC RoadMap

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<tr>
<th>Dual Use Applications</th>
<th>Market Drivers</th>
<th>Enabling Electronics Technology</th>
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<td>Imaging</td>
<td>Diagnostic</td>
<td>Transducers</td>
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<td>High fidelity</td>
<td>EM transceivers</td>
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<td>Mobility</td>
<td>3D &amp; 2.5D integration</td>
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<tr>
<td>Point of Care Diagnostics</td>
<td>Wireless</td>
<td>Microfluidics</td>
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<td>Deterministic</td>
<td>Data storage &amp; analytics</td>
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<td>Continuous monitoring</td>
<td>Wireless communication</td>
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<td>Efficient reagent and sample prep</td>
<td>AI &amp; support algorithms</td>
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<td>Wearable Health Tech</td>
<td>Accurate</td>
<td>Renewable power</td>
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<td>Light weight</td>
<td>Flexible / wearable material</td>
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<td>Power efficient</td>
<td>Biochemical processing</td>
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<td>En Route Medical Care</td>
<td>Reliable in extreme environments</td>
<td>Multimodal sensing</td>
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<td>Data collection, analytics, mobility</td>
<td>Sensor data fusion</td>
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<td>Pain management</td>
<td>SW &amp; HW cybersecurity</td>
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<td>Data security</td>
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2019 Request for Proposals

Army Research Lab
Flexible hybrid and printed electronics for next generation electronics
A. Reference designs for FHE sensor systems
B. FHE Power
C. Artificial Intelligence (AI) for additive manufacturing
D. Mixed mode interconnect and metallization for FHE
E. Human-Machine Interfaces (HMI)
F. Open concepts for sensor and FHE technologies and agile, expedient manufacturing

Air Force Research Lab
Wearable technology for human performance and augmentation
Innovations and technologies that are of specific value to both defense capabilities, in support of the aeromedical mission of the United States Air Force, as well as commercial opportunities, specifically in the areas of smart medtech, digital health, and personalized medicine.
A. Wearable Device for Ambulatory Monitoring Capability
B. Wearable Human-Biochemistry Monitoring Capability
C. Wearable Cuffless Blood Pressure Monitoring Capability
D. Open Concepts for Wearable/Mobile Human-Monitoring/Diagnostic Capabilities
Summary and what I didn’t discuss!

• Wearables do not yet have consumer market pull
• Medical technology is the leading vertical for wearables
Backup Slides
<table>
<thead>
<tr>
<th>Technology readiness level (TRL)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Basic principles observed and reported</strong></td>
<td>Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.</td>
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<tr>
<td><strong>2 Technology concept and/or application formulated</strong></td>
<td>Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.</td>
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<tr>
<td><strong>3 Analytical and experimental critical function and/or characteristic proof of concept</strong></td>
<td>Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.</td>
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<tr>
<td><strong>4 Component and/or breadboard validation in laboratory environment</strong></td>
<td>Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.</td>
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<tr>
<td><strong>5 Component and/or breadboard validation in relevant environment</strong></td>
<td>Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high-fidelity laboratory integration of components.</td>
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<tr>
<td><strong>6 System/subsystem model or prototype demonstration in a relevant environment</strong></td>
<td>Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology’s demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.</td>
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<tr>
<td><strong>7 System prototype demonstration in an operational environment</strong></td>
<td>Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).</td>
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<td><strong>8 Actual system completed and qualified through test and demonstration</strong></td>
<td>Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.</td>
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<tr>
<td><strong>9 Actual system proven through successful mission operations</strong></td>
<td>Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.</td>
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Award Requirements
aka the fine print

- Company/team must have **significant US presence** in the form R&D activities or manufacturing
- **50%** of the work **funds** must be **spent within US operations**
- Primary company leading the proposal must be a US-owned company (Can be waived if the development is critical to US manufacturing capability for select cases)
- **Company/team must be committed to volume manufacturing and provision to the US FHE industry on a right-of-first acceptance basis.** (Applied research conducted by universities does not need to meet this requirement but a pathway to commercialization and or licensing must be envisioned and described)
- **The company/team**, including universities, **must provide a matching share** of the development cost in cash and in-kind contributions (e.g., labor and materials) - **50%** recommended
- **Companies** which are selected for an award, including all partners and/or subcontractors, **must subsequently join SEMI** at the appropriate membership level.
- Companies and organizations which are selected for an award **must agree to terms and conditions** set forth in the SEMI FlexTech Development Agreement before receiving any portion of the award.
## Sensors for detection of physiological signals

<table>
<thead>
<tr>
<th>Form of energy</th>
<th>Parameters</th>
<th>Examples of biosignals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>Voltage, current, resistance, capacitance, inductance, etc.</td>
<td>ECG, EEG, EMG, EOG, ENG</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Displacement, velocity, pressure, acceleration, force, flow, etc.</td>
<td>Blood pressure, pulse wave velocity</td>
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<tr>
<td>Thermal</td>
<td>Temperature, heat flow, conduction, etc.</td>
<td>Body core temperature, skin temperature</td>
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<tr>
<td>Radiant</td>
<td>Visible light, infra-red radio waves, etc.</td>
<td>SpO2, photoplethysmography</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Magnetic flux, field strength, etc.</td>
<td>Magnetoencephalography, flow meters</td>
</tr>
<tr>
<td>Chemical</td>
<td>Chemical composition, pH, etc.</td>
<td>Glucose, cholesterol, creatine kinase</td>
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