SEMI Public Private Partnerships: Wearables Case Study

Stefanie Harvey, Ph.D.

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

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How do we define “wearable”?

What is a wearable?

An electronic device to augment human senses or capabilities <u>worn</u> on an individual

Pre-electronic wearables

Prehistoric Inuit Snow-Goggles, circa 1200 (Canadian Museum of Civilization, 1997).

Table watch → Pocket watch, 1510

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)

JAWBONE®

fitbit.

- 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

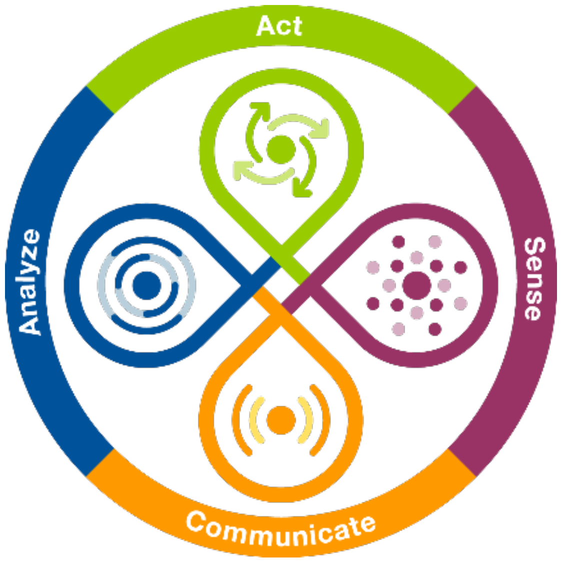
- IoT
- Technology Hype Cycles

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."



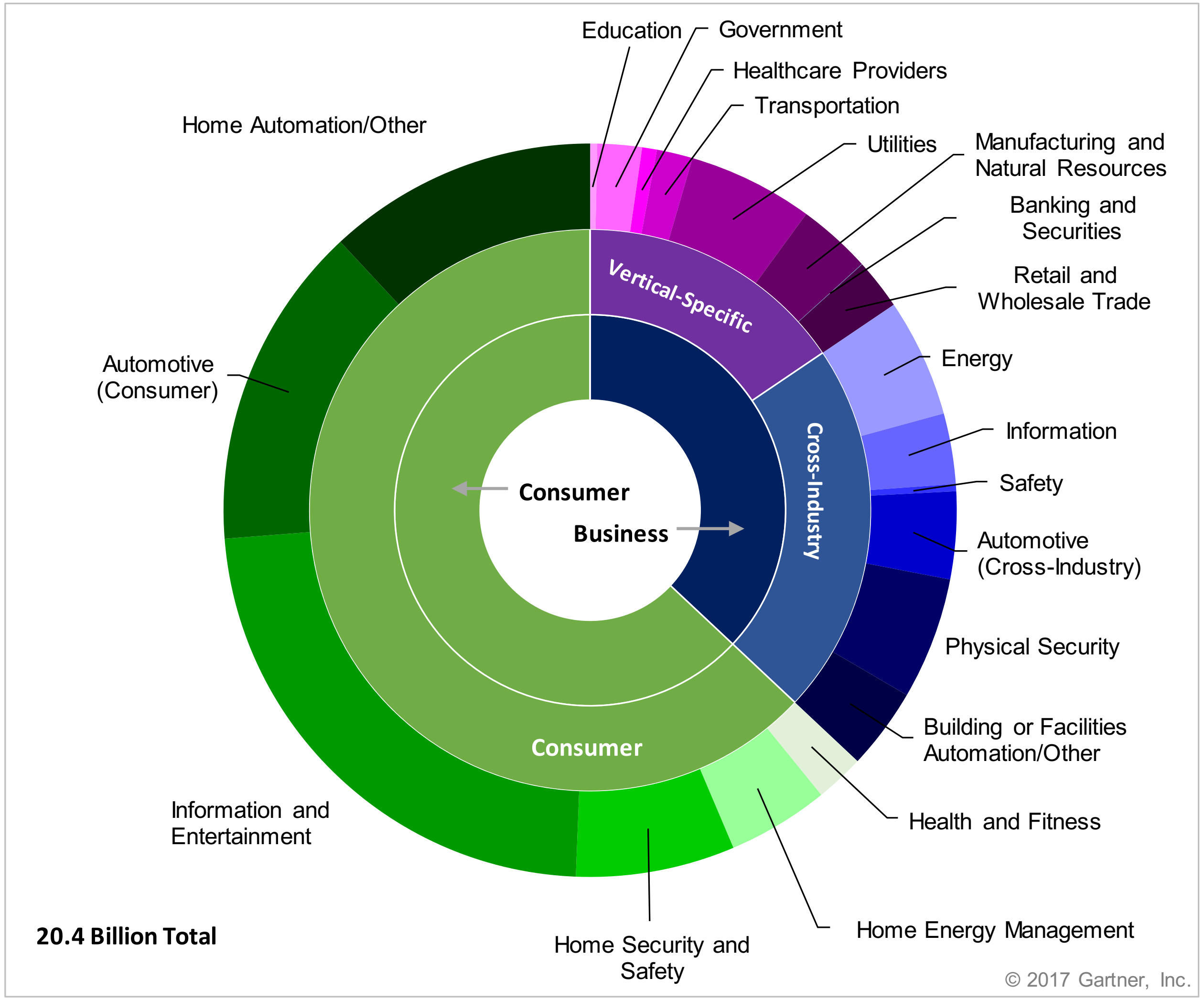
- 20.4 billion devices by 2020
- Business applications well defined
- Consumer lagging
- 33% CAGR through 2020

Source: Forecast: Internet of Things -- Endpoints and Associated Services, Worldwide, 2016, G00321441

Wearables are a subset of IoT devices

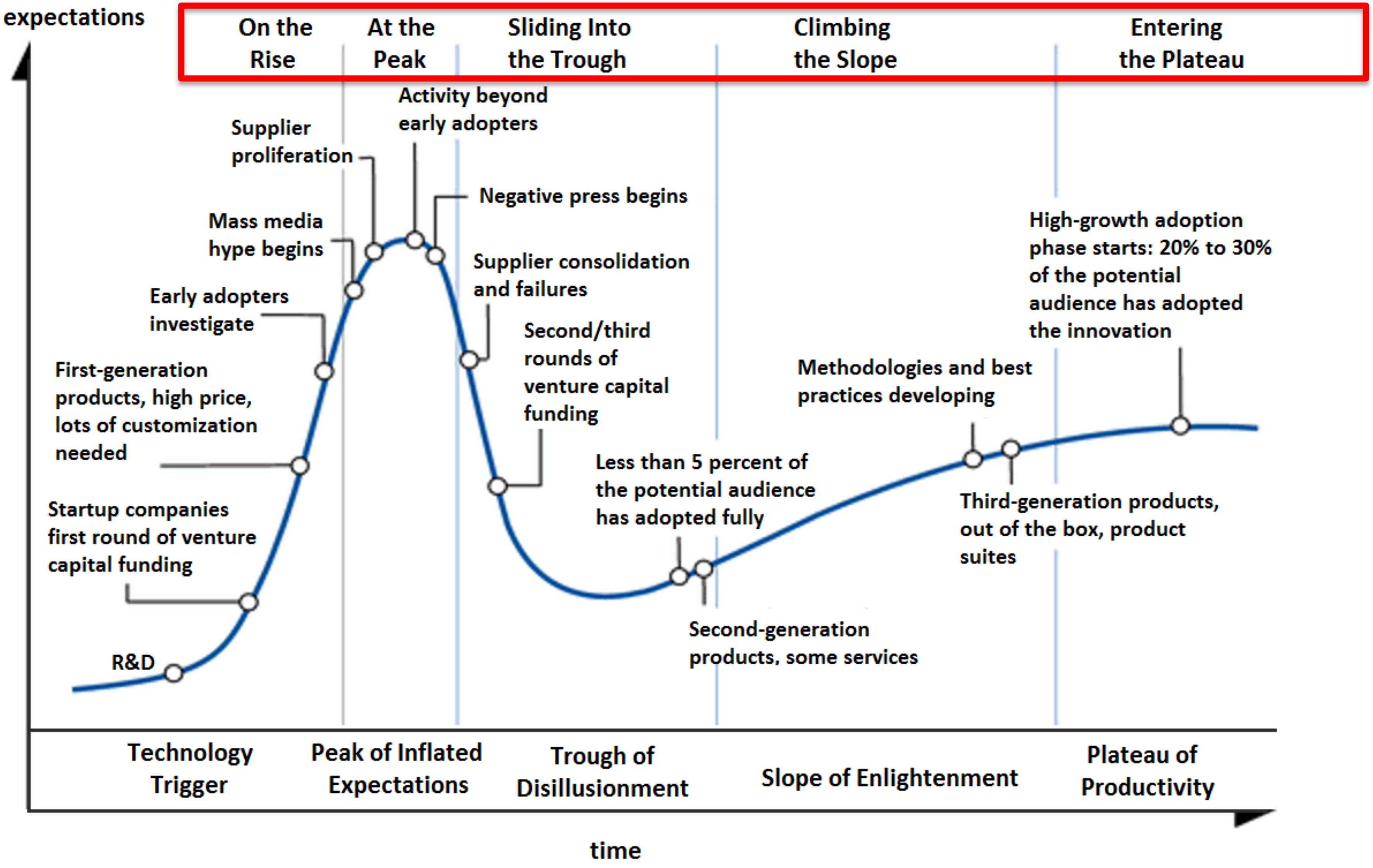
Observations

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



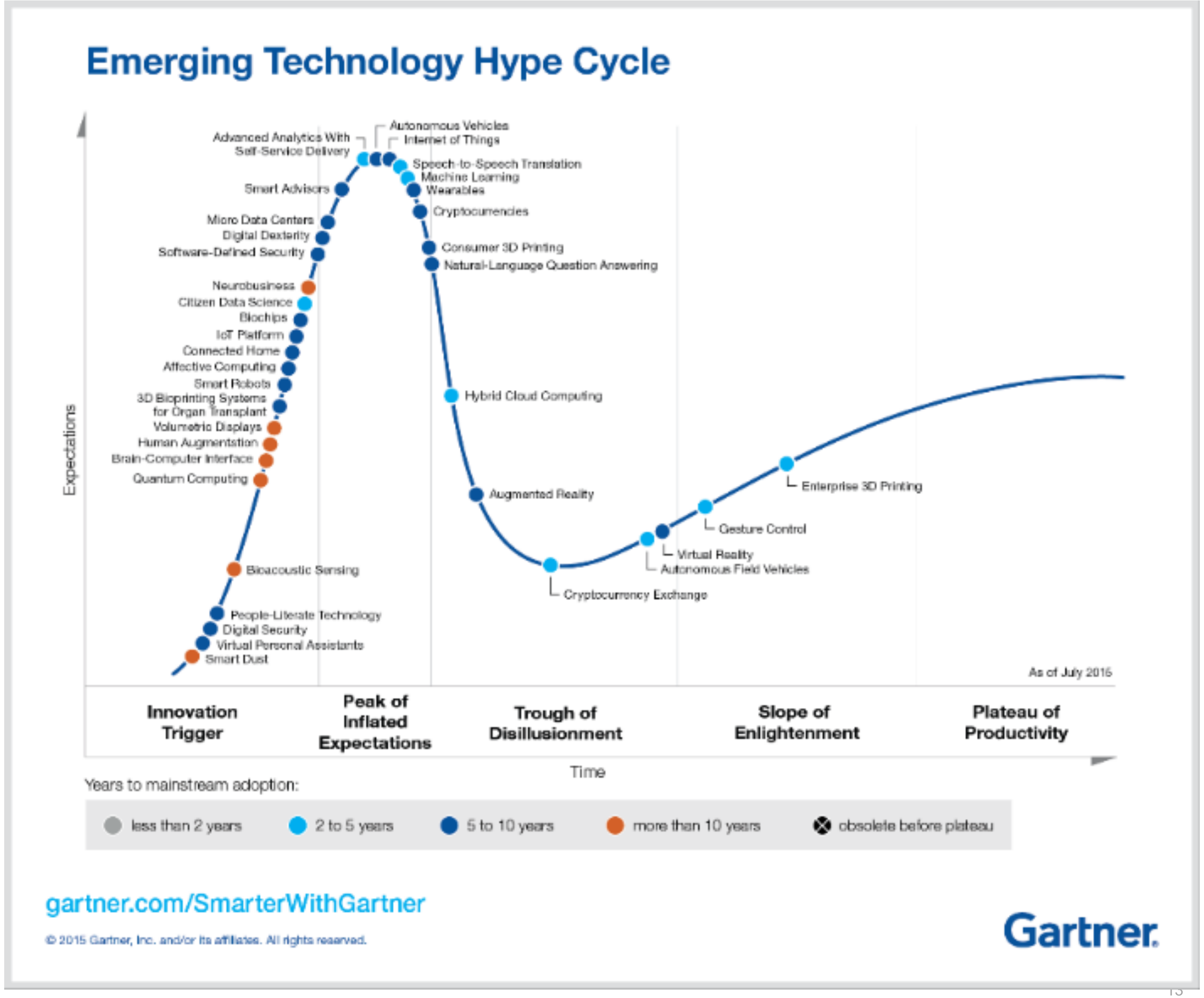
Source: *Forecast: Internet of Things -- Endpoints and Associated Services, Worldwide, 2016, G00321441*

Gartner Hype Cycle



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



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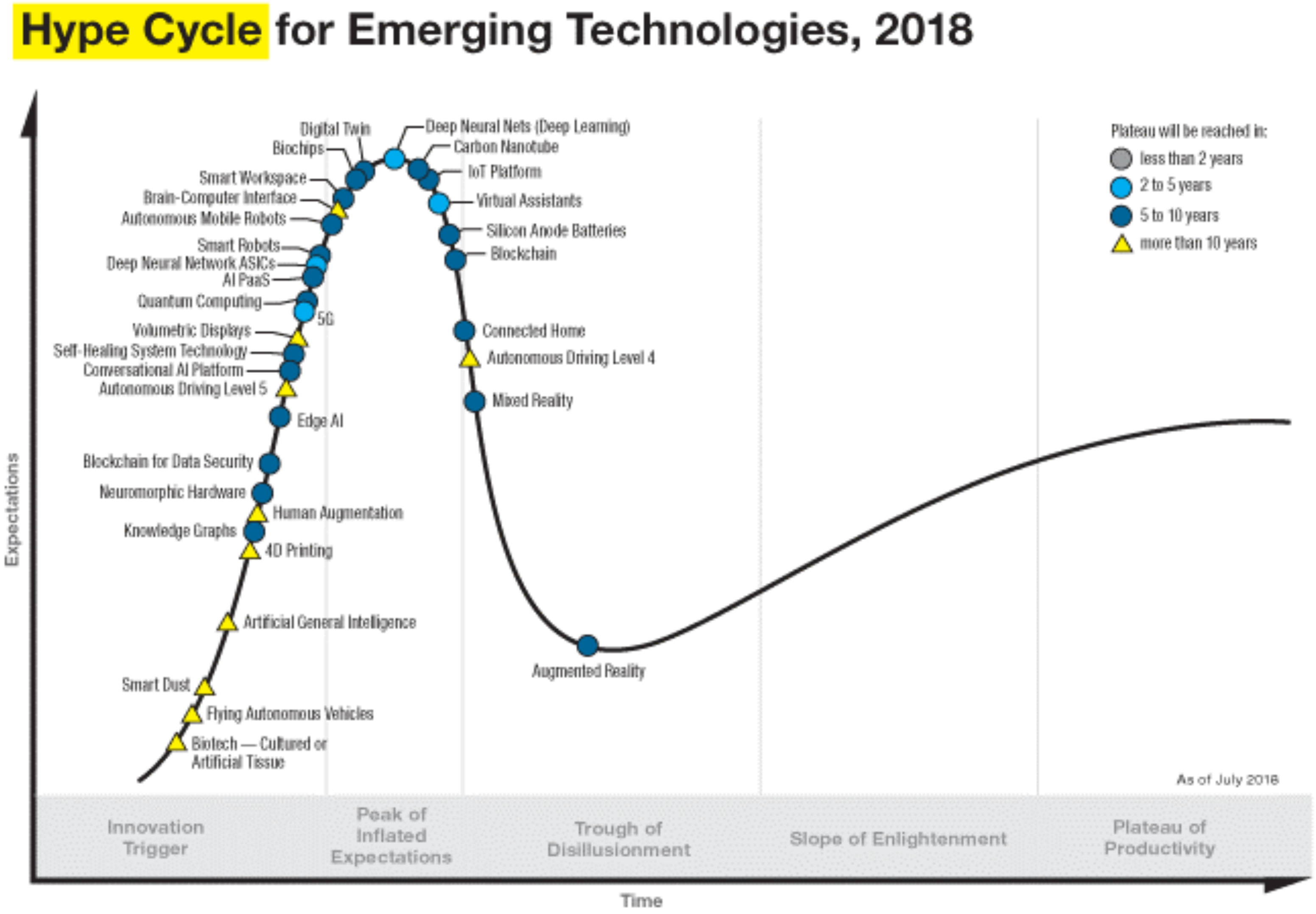
Gartner Hype Cycle For Emerging Technologies, **2018**

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



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Wearables in the Hype Cycle

Data taken from Gartner, 2018
Bolding by speaker

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

Coming out of R&D

Utilizes existing tech

Adopted

CES 2019: A Small Selection of Exhibited Wearables

Withings Move ECG

Willow 2 Breast Pump

Exosystems exoRehab

nreal mixed reality glasses

sphero specdrums

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

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.


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Without this.
amazon
NETFLIX
Tencent 腾讯
NAVER
Google
facebook
LINE
Alibaba.com
JD.京东.COM
Bai du 百度
None of these.

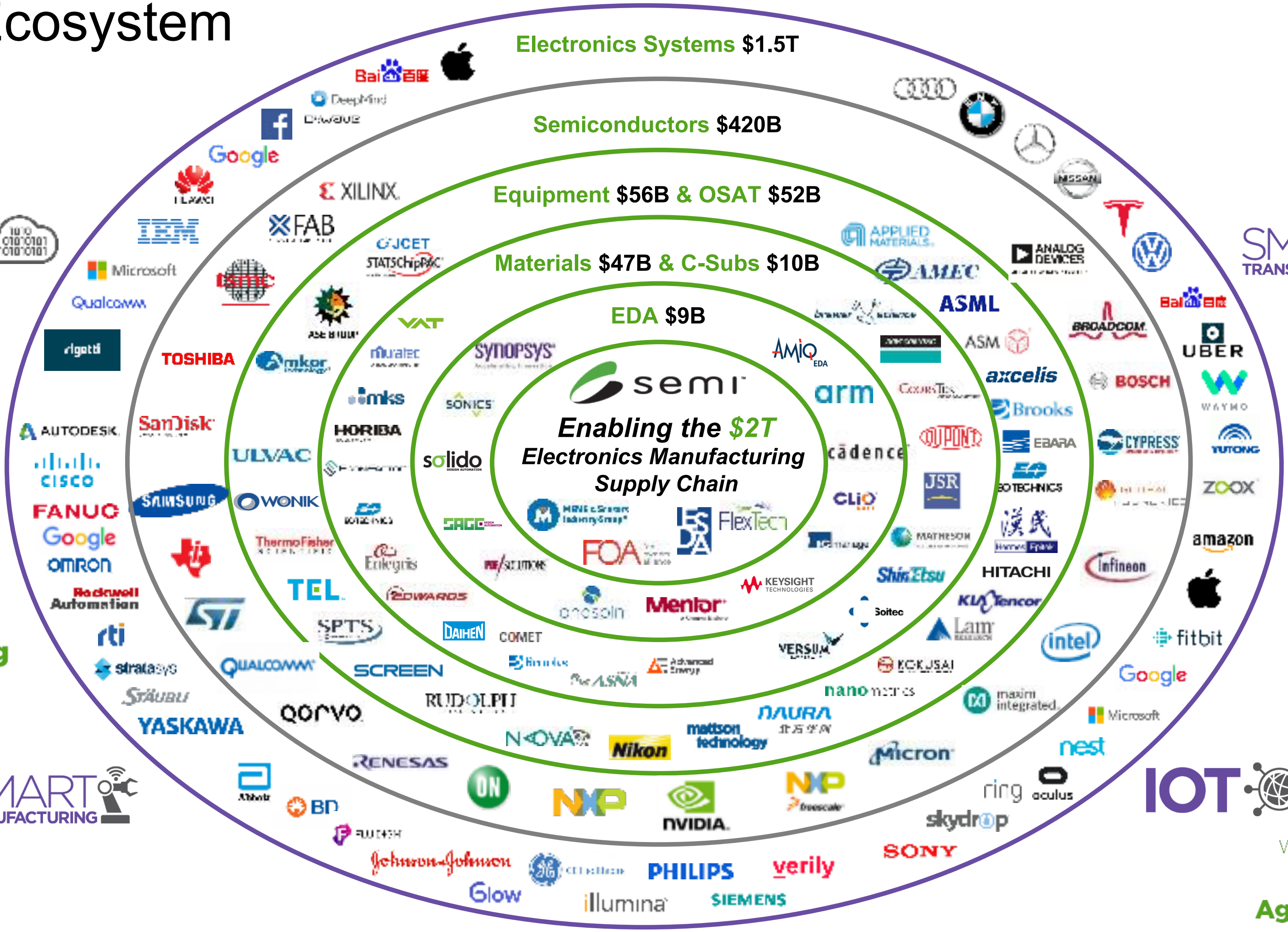
>$2T SEMI's Ecosystem

A.I.
Machine Learning
Blockchain
5G
Bitcoin Mining
Quantum Computing
SMART DATA

DIGITAL WORLD

5TH INDUSTRIAL REVOLUTION

3D Printing
IIoT
Industry 4.0
Realtime Configuration
Robots
Adaptive Manufacturing
SMART MANUFACTURING



Autonomous Vehicles
Trucking
Fleet
SMART TRANSPORTATION
Drones
Driver Assistance

ZERO EMISSION

Smart City
AR/VR
Gaming
Fitness Tracking
IOT
Voice Assistant
Wearables
Smart Home
GPS
Agriculture

SAFETY & WORLD HUNGER

Human Performance Monitoring
CRISPR
Biometrics
SMART MEDTECH
Digital Health
Dosage Monitoring

LIFE SPAN TO HEALTH SPAN

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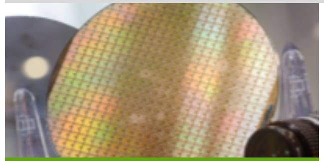
SEMI Connects the Electronics Manufacturing Supply Chain

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



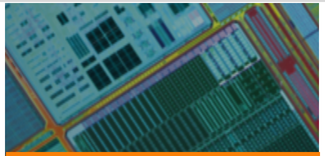
Substrates

Materials

Components

Subassemblies

Equipment



IP

Design

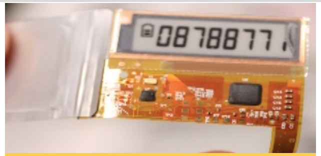
Fabless

Device

Manufacturing

Packaging

Test



System

Integration

Applications

CONNECT ♦ COLLABORATE ♦ INNOVATE

Five SEMI Vertical Application Markets

"Consumer"

Home-related examples
- Wearables
- Smart Lights
- Smart Locks
- Smart Thermostat
- Smart Coffee Pot
- Smart Pet Feeder

"Factory"

Examples
- IIoT
- Industry 4.0
- Machine Learning
- Sensors

"Car"

Examples
- Safety
- Telemetrics
- Infotainment
- Wearables
- Car-to-car, car-to-road
- Driverless cars

"Health"

Examples
- Wireless patient monitoring
- Dose monitoring
- Health and wellness monitoring
- Biometrics, sensing, and diagnostics

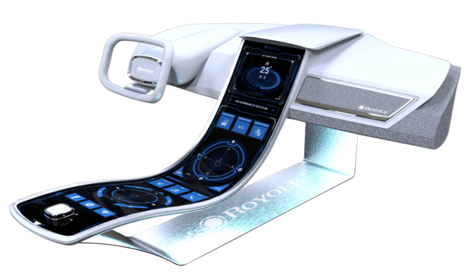
"Data"

Examples
- Secure data sharing
- Analytics
- AI/ML/Big Data
- Cybersecurity
- Blockchain

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)



Royole

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

Platforming

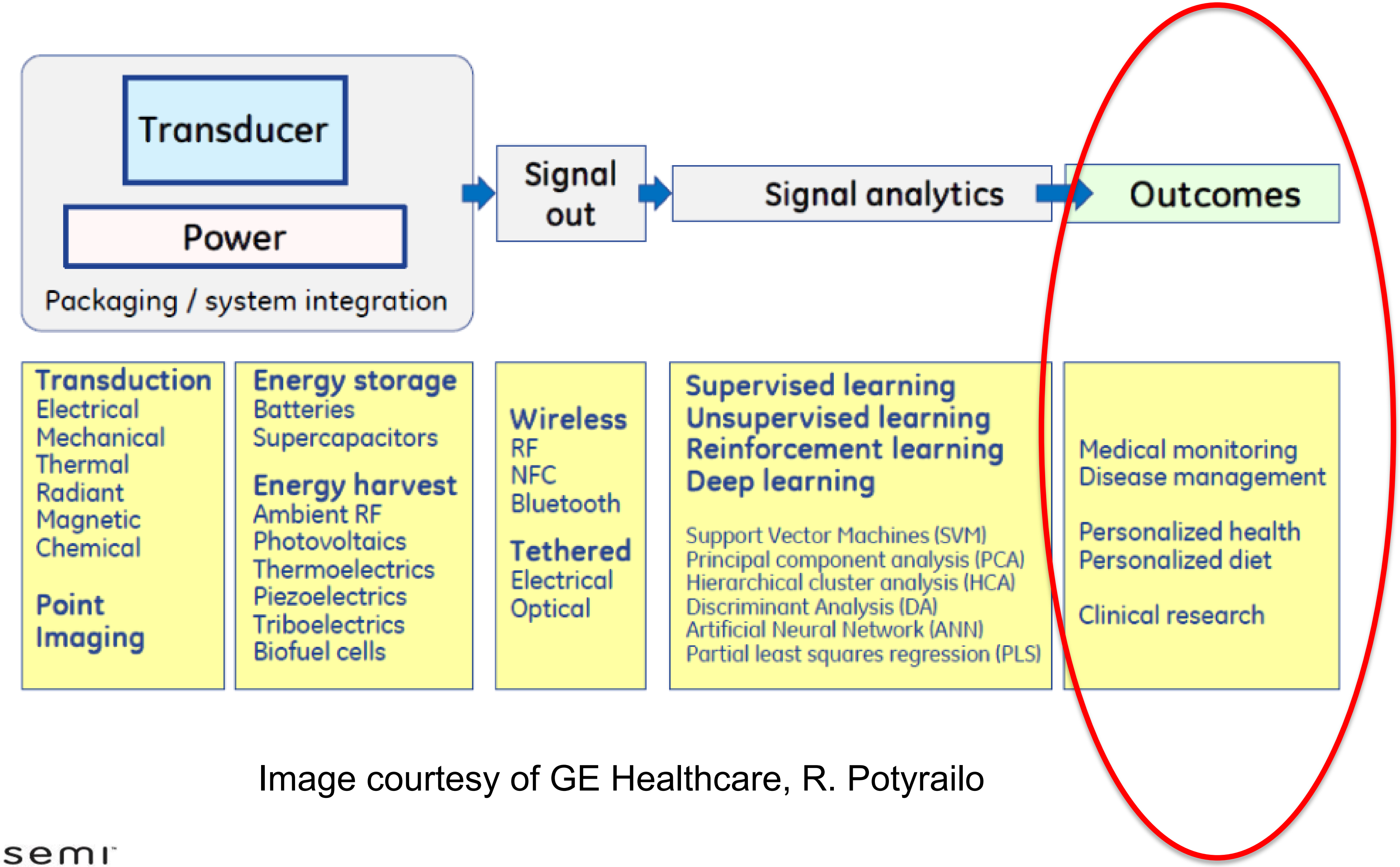


Image courtesy of GE Healthcare, R. Potyrailo

The first three modules are generic to any sensor system

Revisit Wearables from Consumer to Medical

Wearables for Medical Applications

Graphic: GE Research

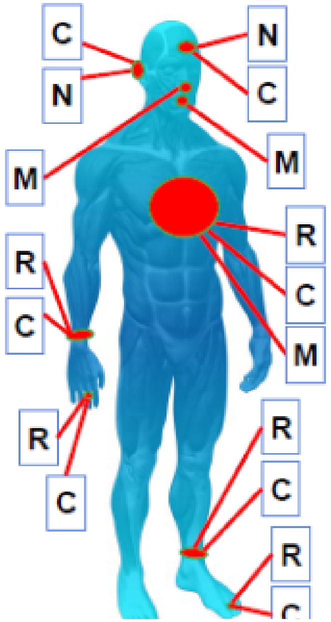
Vital signs
- Heart rate
- Blood pressure
- Respiration rate
- Body/skin temperature
- Blood oxygen saturation level

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

Koydemir, Ozcan, *Ann. Rev. Anal. Chem.* 2018, 11, 127-146

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

Potyrailo , et.al., 2019



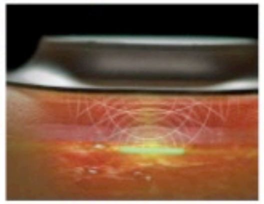
Worn

mymotiv.com

Clothing-integrated

Textile World
2019

Implanted



profusa.com

Ingested

Nature Electronics
2018

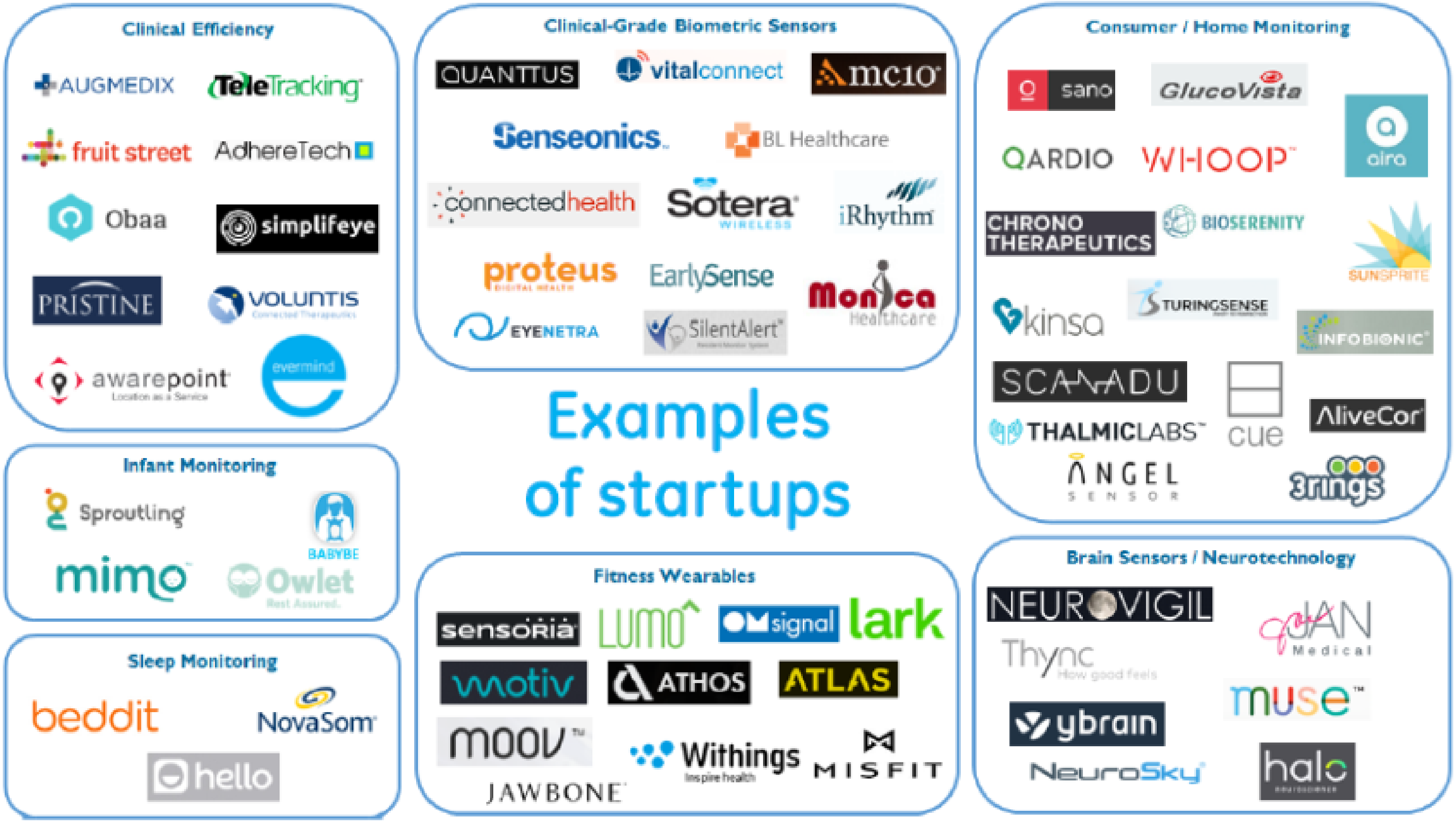
Tattooed

Nature Biotechnology
2019

Skin-interfaced

mc10inc.com

Wearable Sensor Start-Ups



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/

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Large Company Perspective: GE Healthcare (1 of 2)

Physiological sensors: future research directions

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

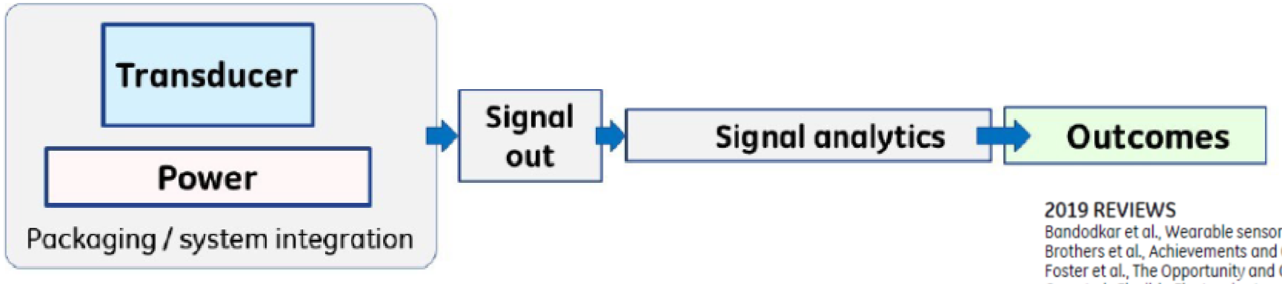
Transducers:
- Detection of trace levels in biomarkers in body fluids
- Hyphenation of transduction modalities for more accurate sensing, elimination of ambient noise
- Reduction/ elimination of biofouling

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



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Someya et al., Toward a new generation of smart skins, *Nature Biotechnology* **2019**, 37, 382
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Yang et al., Wearable and flexible electronics for continuous molecular monitoring, *Chemical Society Reviews* **2019**, 48, 1465-1491

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

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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

2012 Launched Nano-Bio Mfg. Consortium (NBMC)

- 17 projects – $15M combined investment

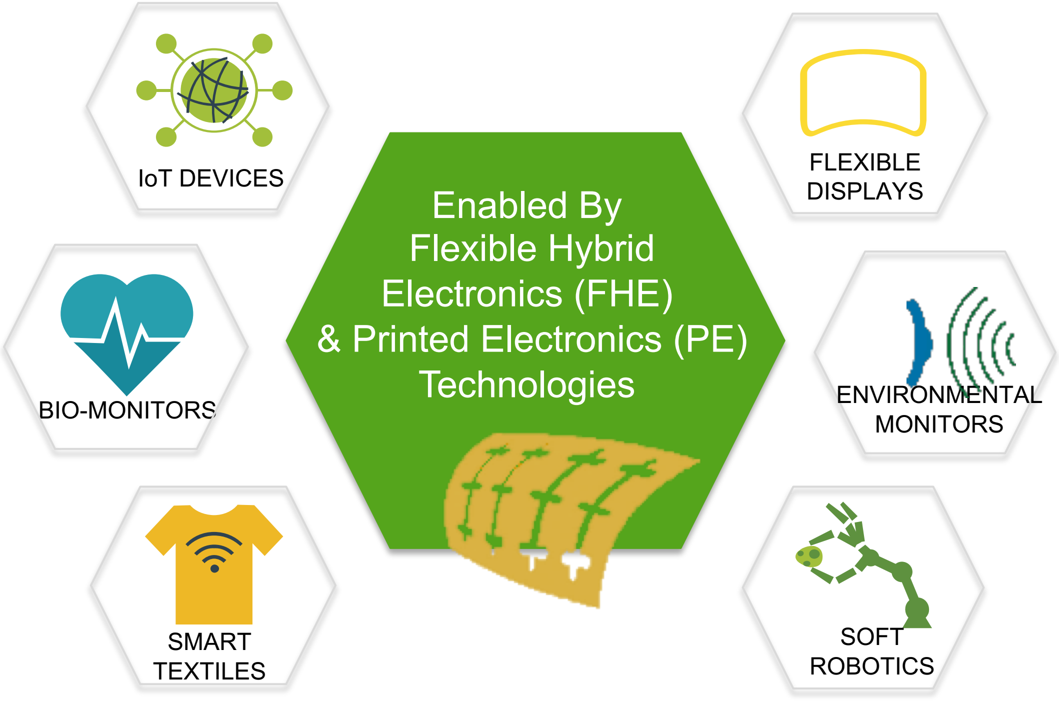
2015 Launched Manufacturing Innovation Institute – Flexible Hybrid Electronics - NextFlex

- $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

Industrial Partner Objectives & Market Drivers

Government & Commercial Strategy Alignment

US Government Mission

Governing Council

Go-To-Market Advisory Group

Technical Council

R&D Projects

R&D Projects

R&D Consortia

Flexible Hybrid Electronics Supply Chain Development

FlexTech

- CMOS integration
- Power
- Radio & communications
- Sensing, warnings, wearable displays

ARL

Flexible, Wearable Human Performance Monitoring

nbmc
Nano-Bio Materials Consortium

- Human performance monitoring/augmentation
- Medical application
- Wearable devices & subsystems

AFRL

Pilot Manufacturing Consortium

Flexible Hybrid Electronics Manufacturing

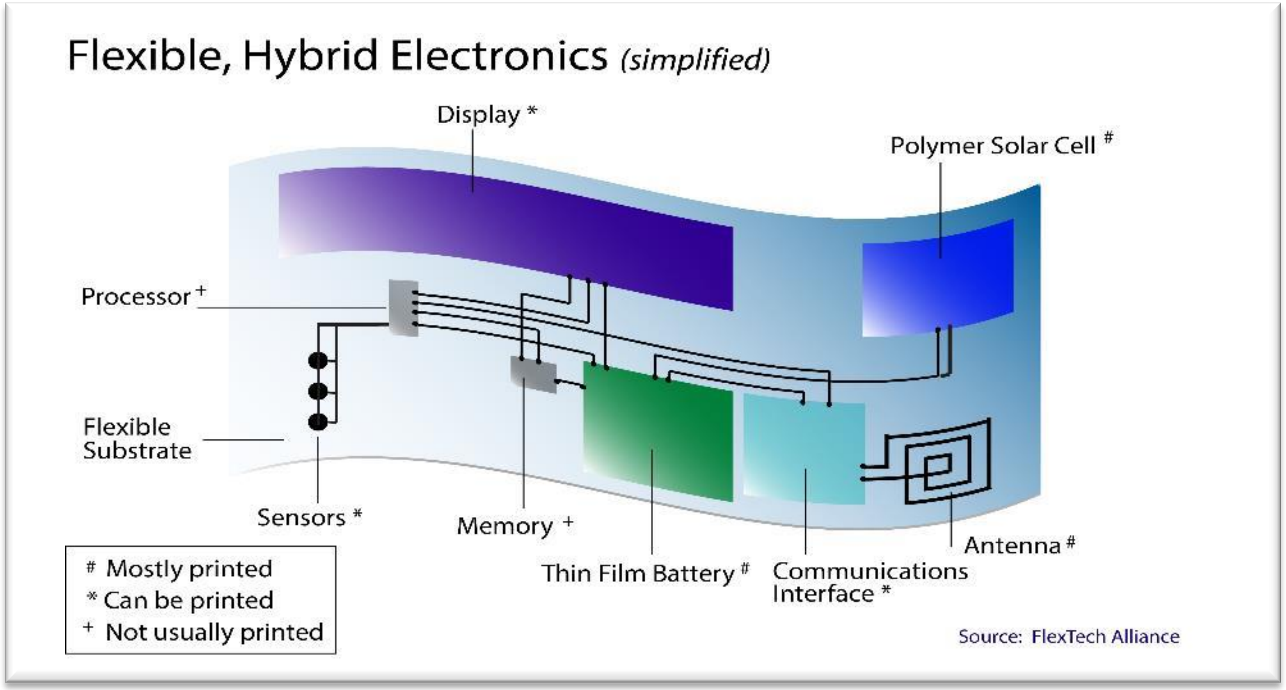
NEXTFLEX
America's Flexible Hybrid Electronics Manufacturing Institute

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

Manufacturing USA

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

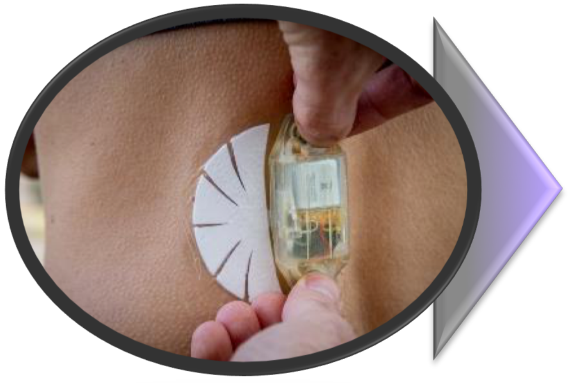
1. Assemble investment partners and governing council
2. Identify needs and challenges
3. Assess the technology landscape (technical council)
4. Issue a request for proposal
5. Fund projects – typically at a 50% cost share

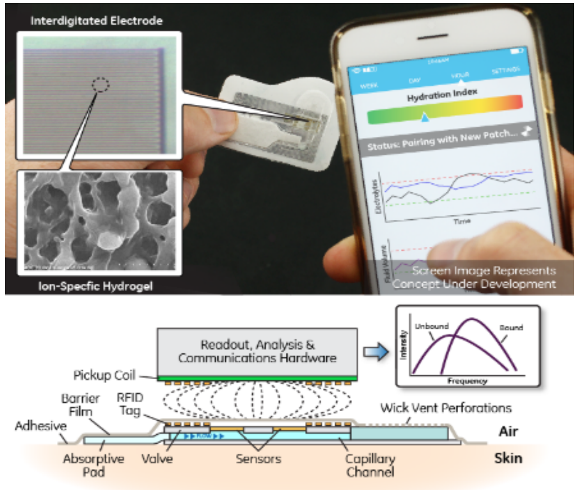
- Q2 2017
- Q4 2017
- Q2 2018
- Q1 2019
- Q2 2019

Power Initiative Example

Thin Film Power Source	ITN Energy Systems
Printed Battery Materials	NovaCentrix
Flexible Printed Battery	Imprint energy
Thin Film Power Source	Custom Electronics, Inc.

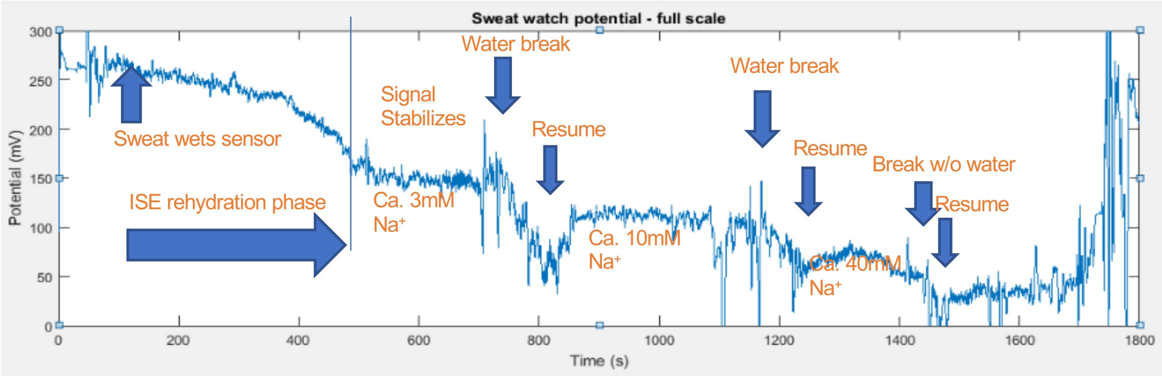
Flexible, Non-invasive Wearable for Dynamic Assessment of Hydration Status





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:

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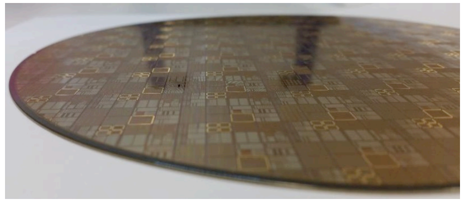
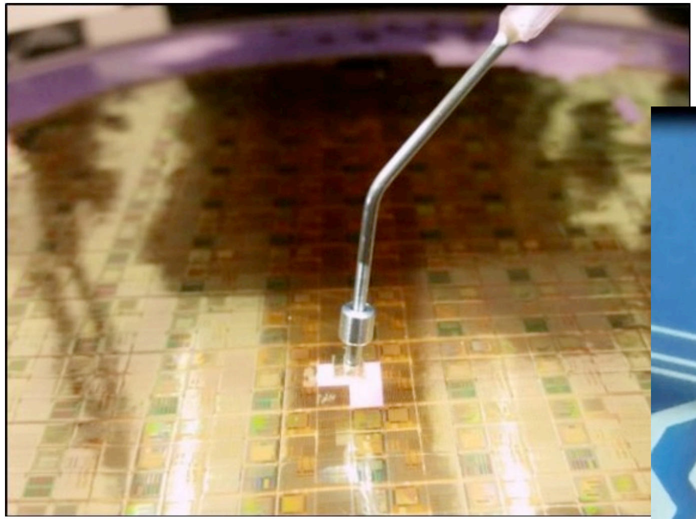
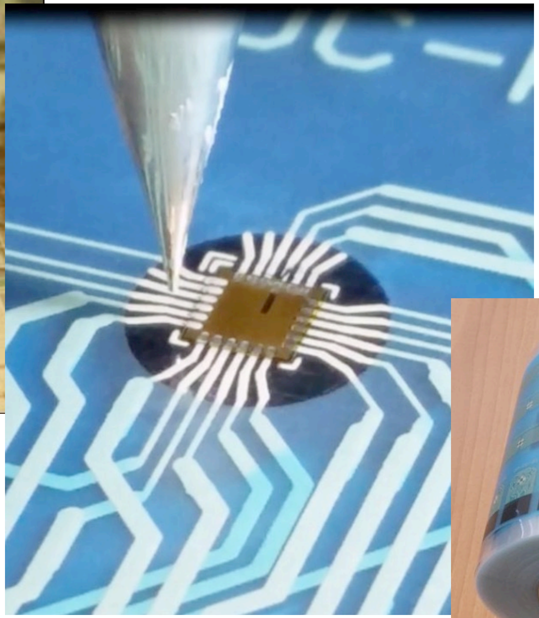
Flexible High Performance ICs

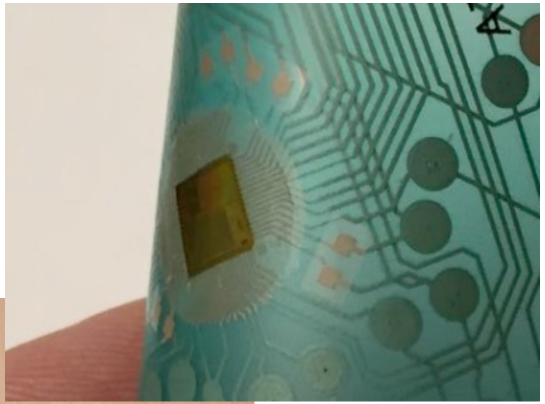
American Semiconductor Inc. Ultra-thin CMOS

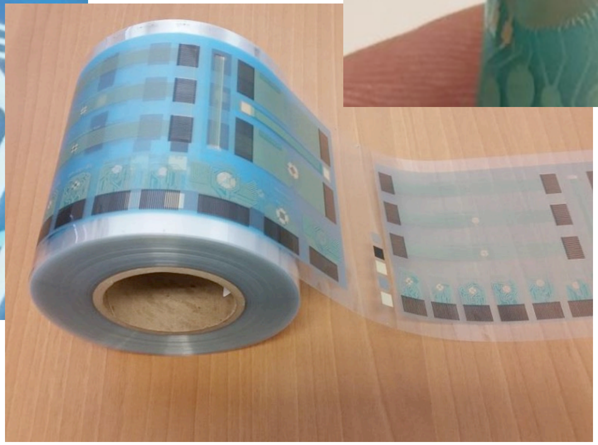
molex
one company > a world of innovation
Assembly & multi-layer flexible PCB











CMOS wafer prep

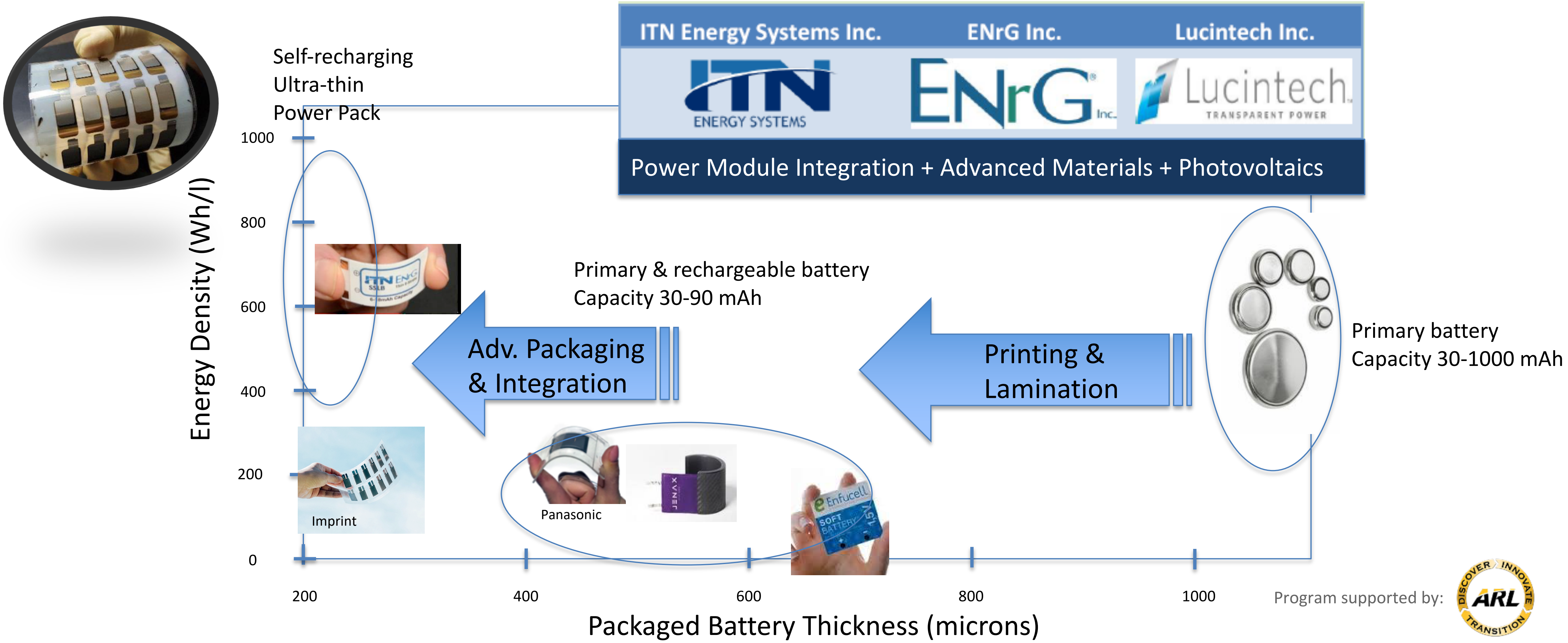
Pick & Place

3D Additive Interconnection

Roll to Roll Manufacturing

Program supported by:

Thin Light Weight Renewable Power Sources



Current Project: ITN, ENrG, Lucintech, University of Rhode Island

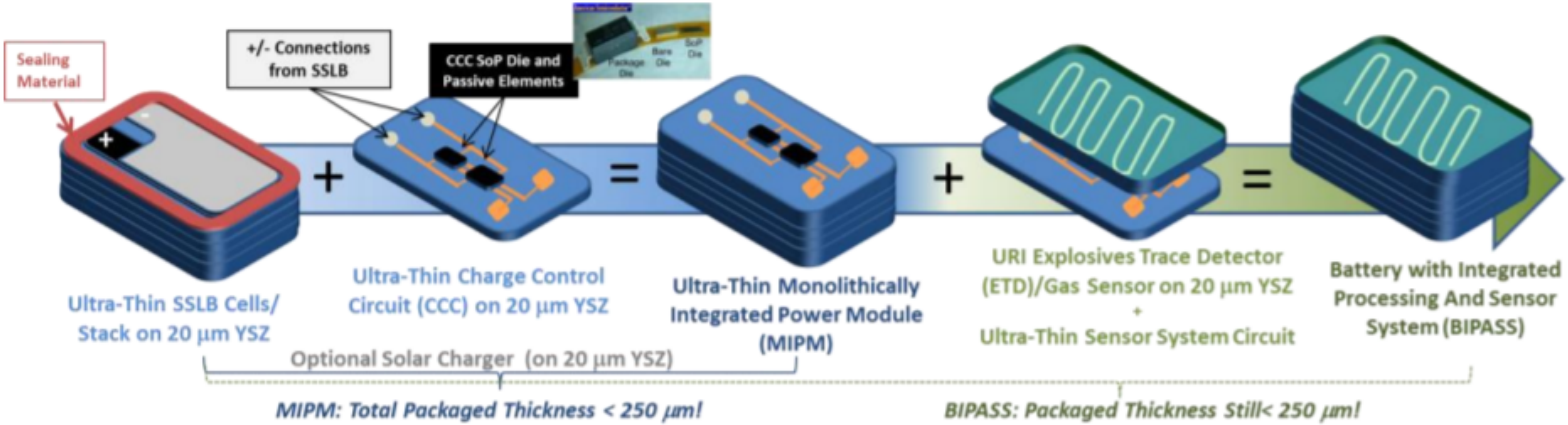


Figure 3. Schematic illustration of the integration of the proposed thinned, high performance silicon microelectronics on ultra-thin YSZ circuit board to enable a new MIPM and BIPASS products.

Technology Landscape: Representative Programs

Research and Development | Demonstration R&D | System Integration R&D | Rel Eval | Manufacturing Dev | Manuf Qual | Pilot Manufact Ramp

TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9

MR1	MRL2	MRL3	MRL4	MRL5	MRL6	MRL7	MRL8

MARKET DRIVERS		
Power	*Ultra thin flexible integrated power pack*	
Flexible PCB	*Printed Interconnect & Resistor, Flexible Ceramic*	*Printed Passives for FHE*
Sensors (1)	*Non-Invasive Bio Fluid; Saliva, Sweat Sensors*	*Gen 2 Sweat Sensor* *Oral Biochemistry Sensing*
Sensors (2)	*Highly Flexible Audio Enabled Hybrid Smart Tags*	
Wireless	*Self Powered Wireless Sensors*; *Wearable Device for Dynamic Assessment of Hydration*	
IC Integration	*FHE Direct Chip Attach*	*Ultra Thin Die Assy*
System	*ECG Biomarker Sensor*; *Microfluidics for Sweat Biomarker Sensors*	*Flexible Smart Wound Dressing with On Demand O2 Release and Sensing*
HMI	*Audio, Display, Capacitive Gel Contact Electrodes*	
Software	*On Board SW (sense and signal conditioning), API, PC-Host User Interfaces*	*Printing on Complex Surfaces*
3D Printing	*Conductive & Dielectric 3D Equipment Development with in-situ Sintering*	*3D Patterning of Embedded HFE*
Machine Tooling		*Implementing FHE Prototype and Production.*
FHE Reliability	*Bend Testing Criteria & Evaluation, Environmental (high temp/humidity) Testing*	*Mechanical Test Methods*

NBMC RoadMap

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

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

Technology readiness level (TRL)		Description
1	Basic principles observed and reported	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.
2	Technology concept and/or application formulated	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.
3	Analytical and experimental critical function and/or characteristic proof of concept	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.
4	Component and/or breadboard validation in laboratory environment	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.
5	Component and/or breadboard validation in relevant environment	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.
6	System/subsystem model or prototype demonstration in a relevant environment	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.
7	System prototype demonstration in an operational environment	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).
8	Actual system completed and qualified through test and demonstration	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.
9	Actual system proven through successful mission operations	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.

Source: GAO simplification of agency documents. | GAO-16-410G

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

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

McAdams, E.; Krupaviciute, A.; Gehin, C.; Dittmar, A.; Delhomme, G.; Rubel, P.; Fayn, J.; McLaughlin, J.,
Wearable electronic systems: Applications to medical diagnostics/monitoring. In *Wearable monitoring systems*, Springer: 2011; pp 179-203