

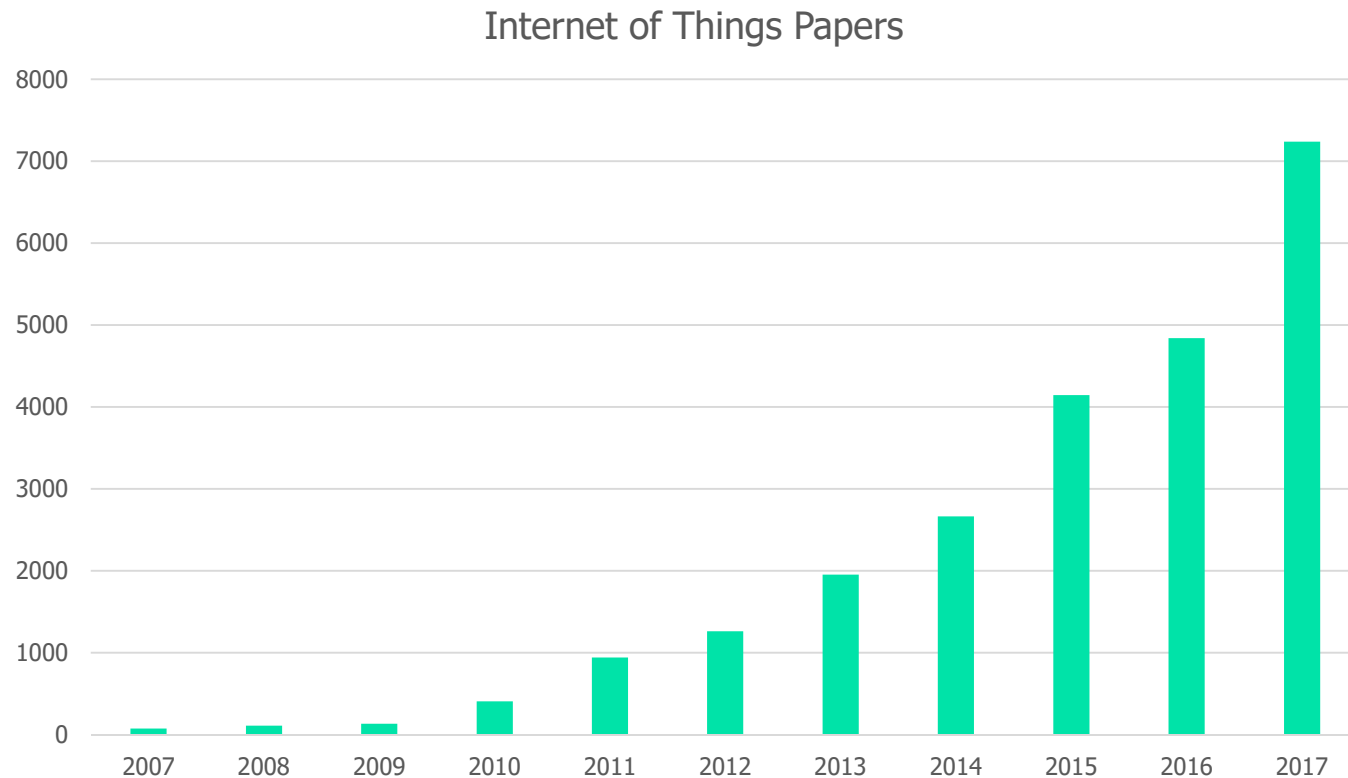


Rise of the Internet of Things

Tarek Abdelzaher
Dept. of Computer Science
University of Illinois at Urbana Champaign

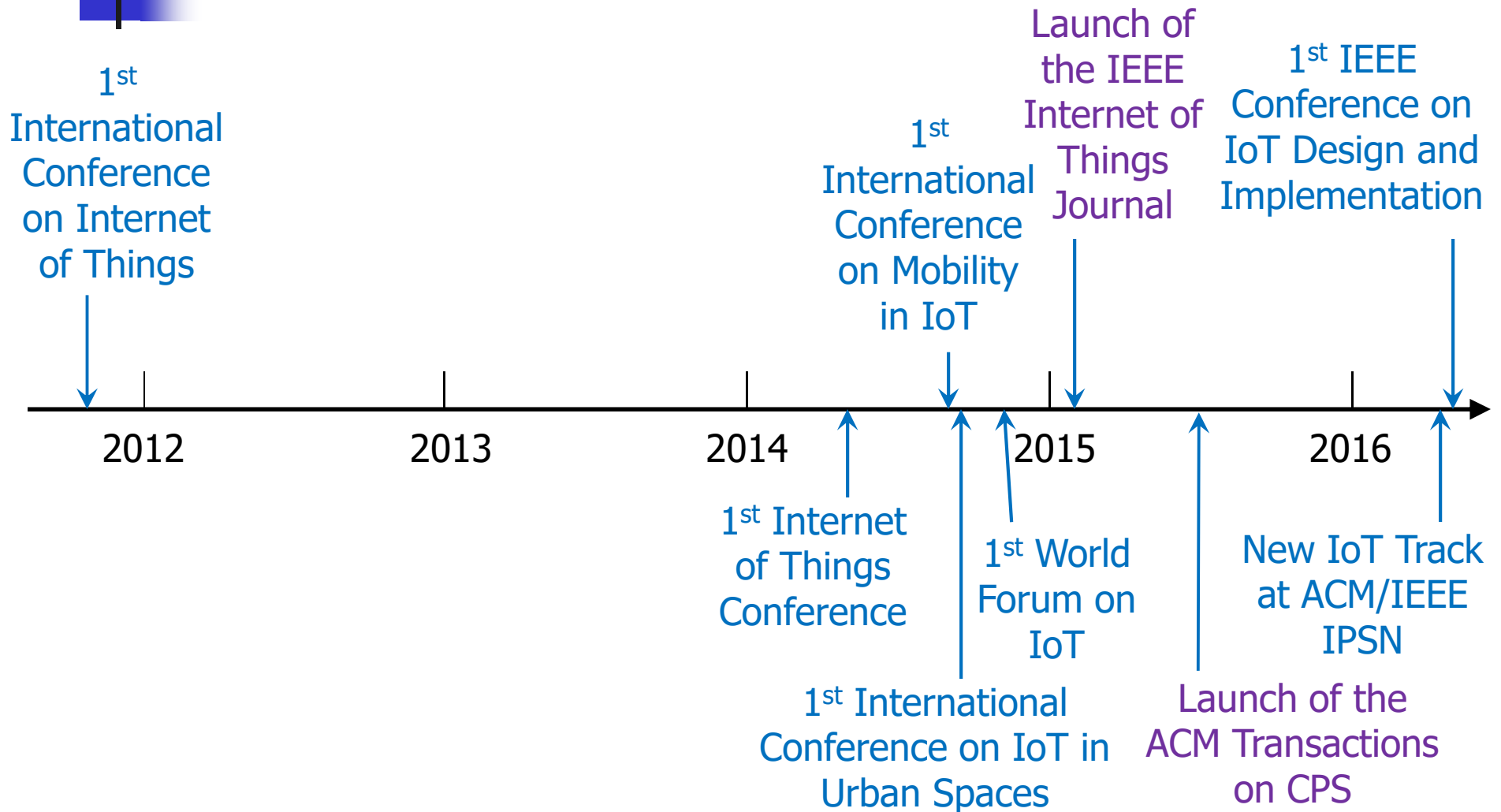
Publications on the Internet of Things

- According to the Engineering Village database (computing and Engineering publications)





Publication Venues



Enabling Technologies

Source: Texas Instruments

Wearables

- Entertainment
- Fitness
- Smart watch
- Location and tracking



Building & Home Automation

- Access control
- Light & temp control
- Energy optimization
- Predictive maintenance
- Connected appliances



Smart Cities

- Residential E-meters
- Smart street lights
- Pipeline leak detection
- Traffic control
- Surveillance cameras
- Centralized and integrated system control



Smart Manufacturing

- Flow optimization
- Real time inventory
- Asset tracking
- Employee safety
- Predictive maintenance
- Firmware updates



Health Care

- Remote monitoring
- Ambulance telemetry
- Drugs tracking
- Hospital asset tracking
- Access control
- Predictive maintenance



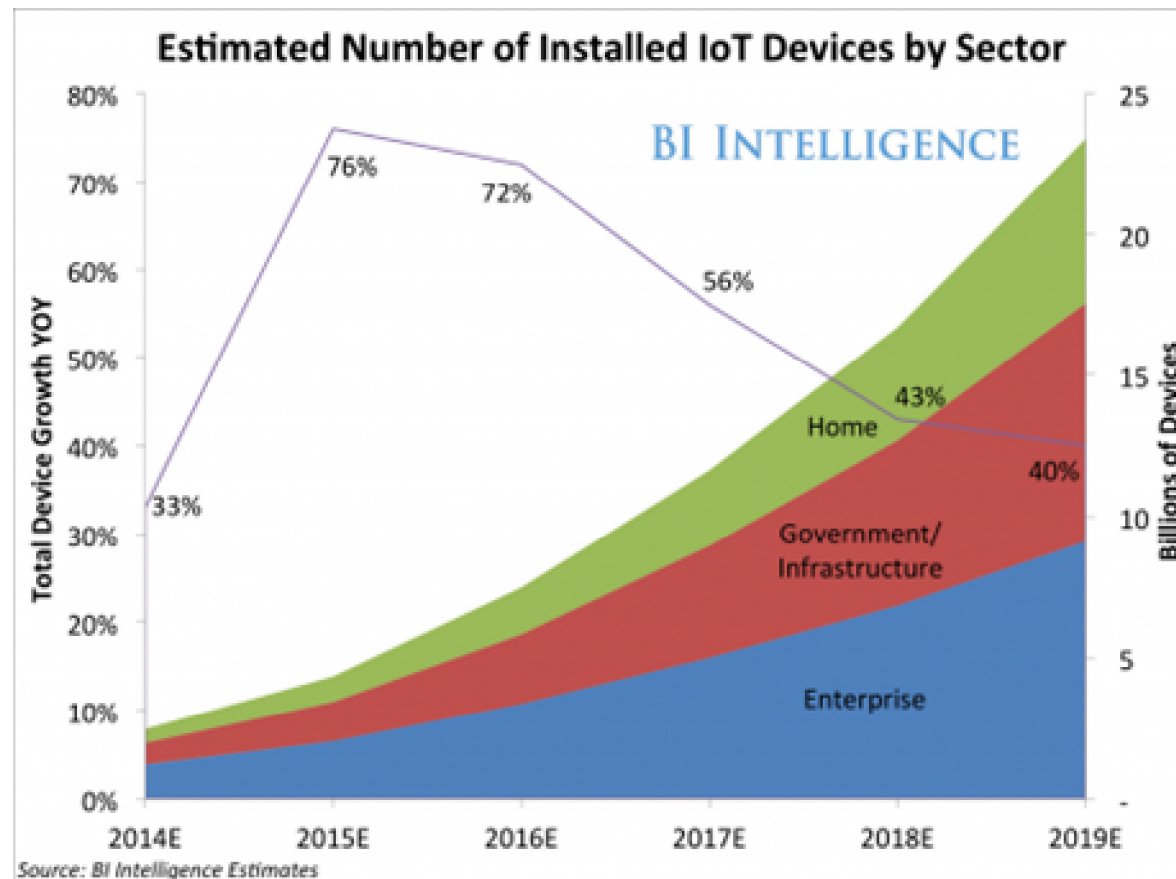
Automotive

- Infotainment
- Wire replacement
- Telemetry
- Predictive maintenance
- C2C and C2I



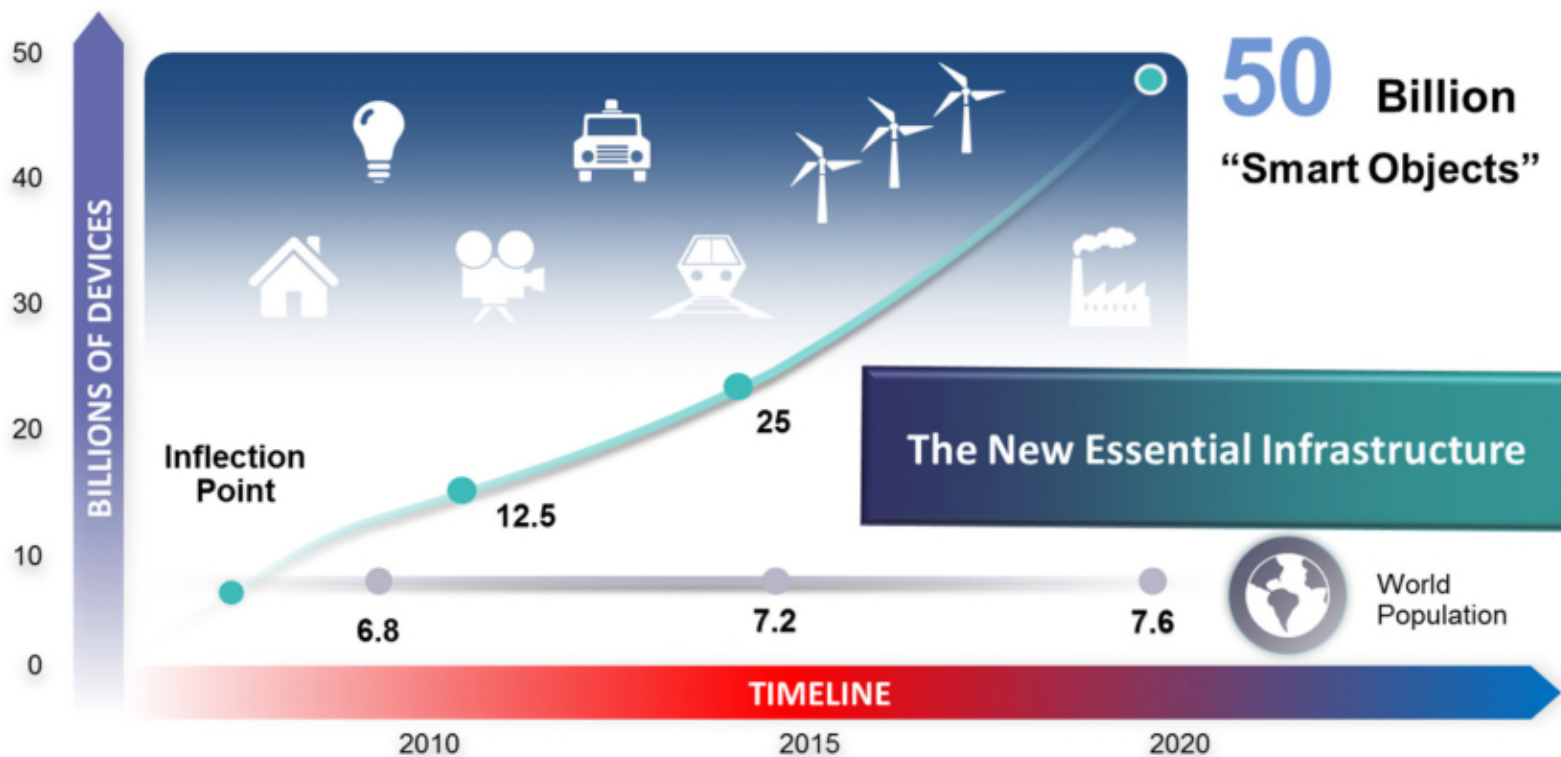
IoT Projections

- Estimated IoT Devices Growth (according to Business Insider)



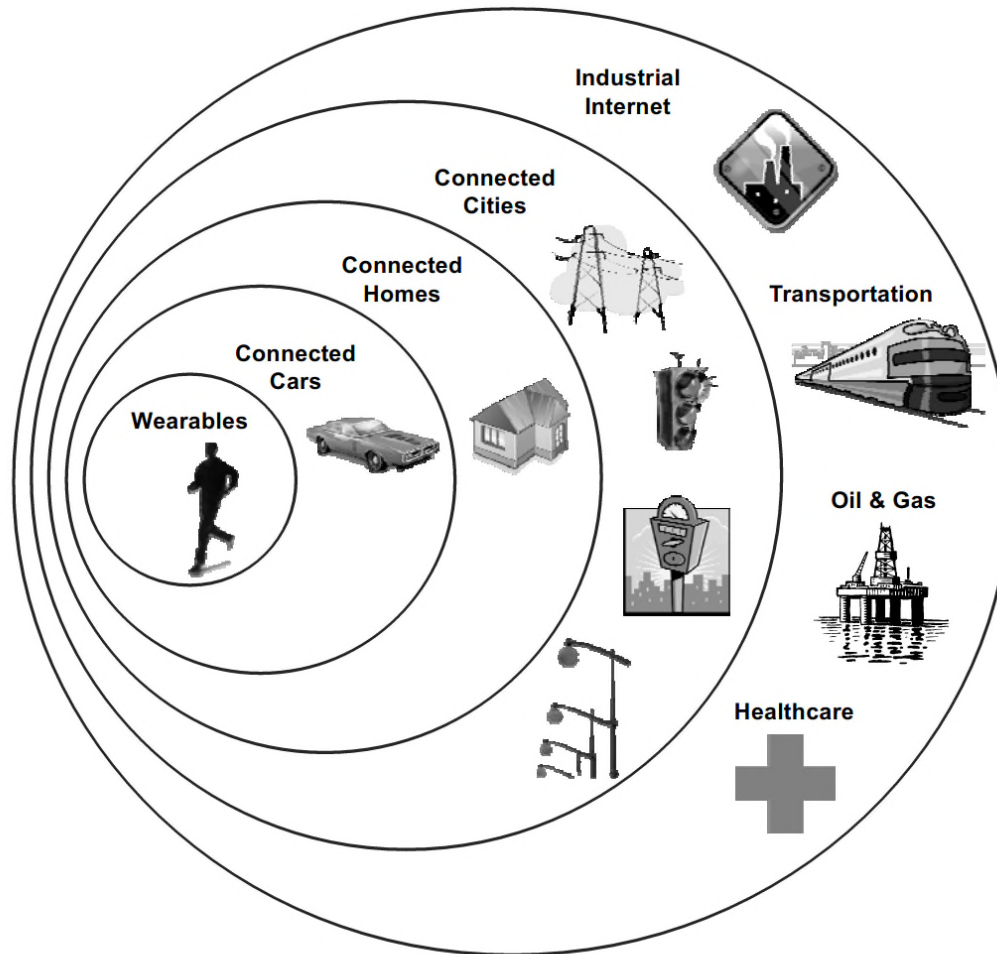
IoT Projections

- Estimated IoT Devices Growth (according to Cisco)



Application Domains

(Source: Goldman Sachs)







The IoT Market: Beyond Consumer-side Devices



Application Categories












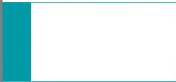






(Source: IBM)

	Banking	Healthcare	Automotive	Retail	Transport	E&U
 Monetize	Cash replacement solutions Mobile Banking	Paid home care family services	Pay-per-drive car rental	Cash replacement Sensor enabled Loyalty cards	Paid Alerts to travellers Congestion charging	Pay-per-use energy
 Optimize	Optimized Cash management	ER Bed Resource Mgmt	Component predictive replacement Fleet mgmt	Delivery and stock replenishment optimization Store layout optimization	Smart Cities Traffic mgmt Airport Management	Delay non-essential supply during peak loads
 Extend	Banking the un-banked Biometrics Smarter Subsidies	Life style monitoring	In-car Movies, Music, Games Highly Automated Driving	Smart Vending Machines Delivery Lockers	Mobility Services	Smart home services
 Control	Remote ATM Management Dynamic Authorization	Remote Hospital environment Mgmt	Remote Drive-train optimization	Store energy mgmt Store parking mgmt Dynamic price labels	Crowd mgmt Timetable mgmt Asset mgmt	Remotely control consumer devices

Application Settings

(Source: McKinsey)

Size in 2025¹
\$ billion, adjusted to 2015 dollars

Settings	Total = \$3.9 trillion–11.1 trillion		Description	Examples	
 Human		170– 1,590	Human	Devices attached to or inside the human body	Devices (wearables and ingestibles) to monitor and maintain human health and wellness; disease management, increased fitness, higher productivity
 Home		200– 350	Home	Buildings where people live	Home controllers and security systems
 Retail environments		410– 1,160	Retail environments	Spaces where consumers engage in commerce	Stores, banks, restaurants, arenas—anywhere consumers consider and buy; self-checkout, in-store offers, inventory optimization
 Offices		70– 150	Offices	Spaces where knowledge workers work	Energy management and security in office buildings; improved productivity, including for mobile employees
 Factories		1,210– 3,700	Factories	Standardized production environments	Places with repetitive work routines, including hospitals and farms; operating efficiencies, optimizing equipment use and inventory
 Worksites		160– 930	Worksites	Custom production environments	Mining, oil and gas, construction; operating efficiencies, predictive maintenance, health and safety
 Vehicles		210– 740	Vehicles	Systems inside moving vehicles	Vehicles including cars, trucks, ships, aircraft, and trains; condition-based maintenance, usage-based design, pre-sales analytics
 Cities		930– 1,660	Cities	Urban environments	Public spaces and infrastructure in urban settings; adaptive traffic control, smart meters, environmental monitoring, resource management
 Outside		560– 850	Outside	Between urban environments (and outside other settings)	Outside uses include railroad tracks, autonomous vehicles (outside urban locations), and flight navigation; real-time routing, connected navigation, shipment tracking

Smart Cars

Converging Technologies

Electric Vehicle
Electric Smart Grid
Connected Vehicle
Autonomous Vehicle



Vehicle to Vehicle
V2V

• Communication



Vehicle to Device
V2D

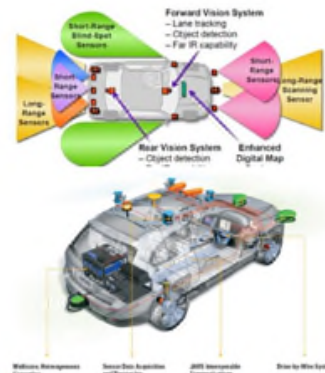
• Telematics



Vehicle to Grid
V2G + G2V

• Charging Stations

Internet of Vehicles
Vehicle to Internet



Vehicle to Infrastructure
V2I

• Communication

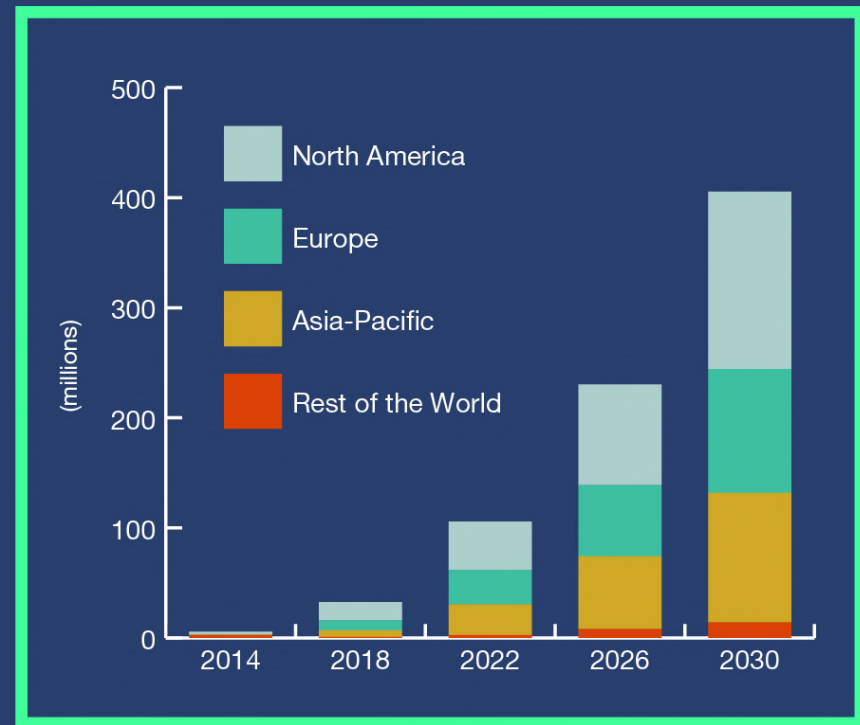
Smart Cars

- Cars will become connected to the “cloud” and share driving data.

(ABI Research)

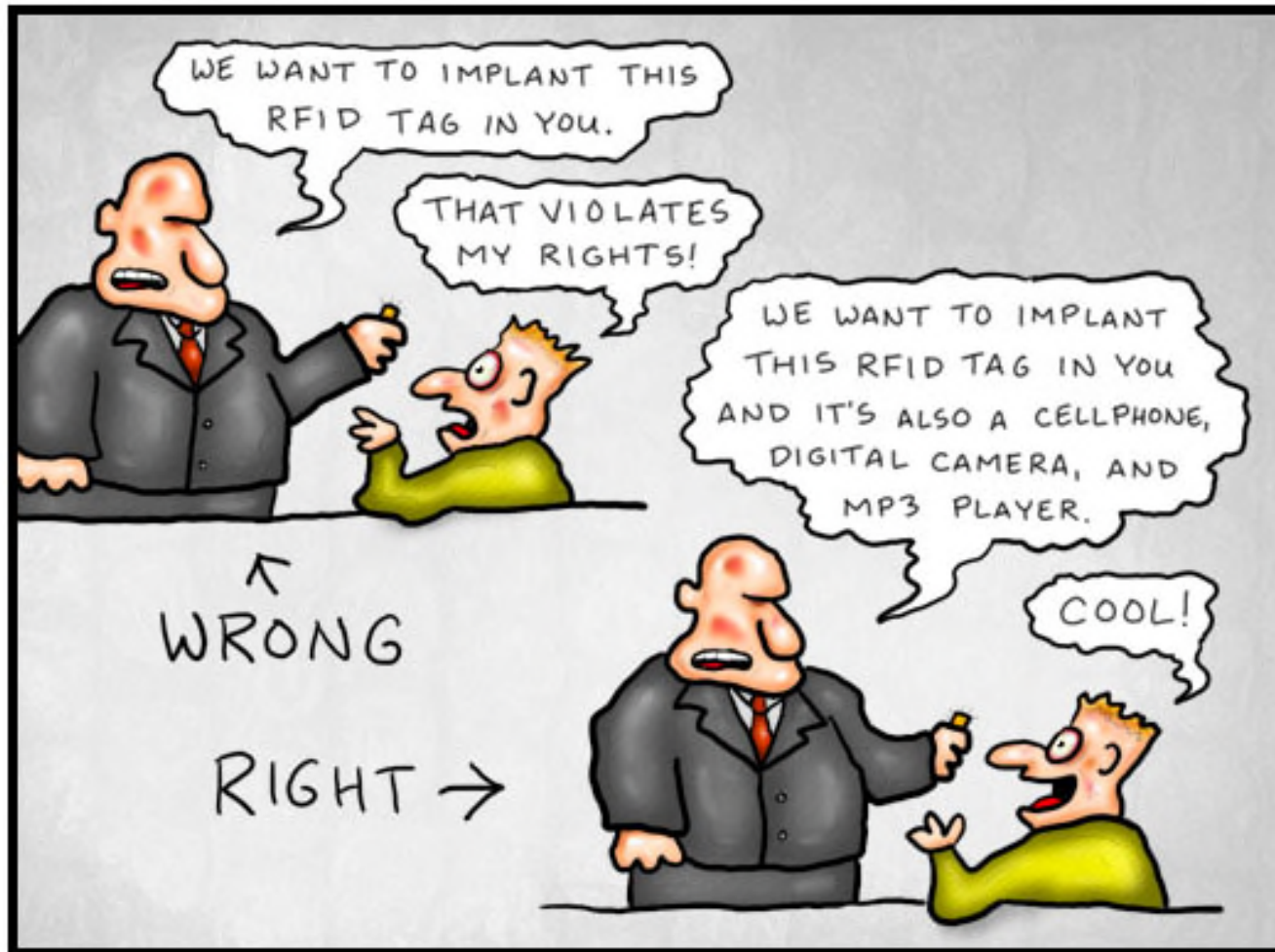
Registered Vehicles with IoT Application by Region

World Market, Forecast: 2013 - 2030



Source: ABI Research

Smart Car Applications and Data Privacy





Smart Car Applications and Data Privacy

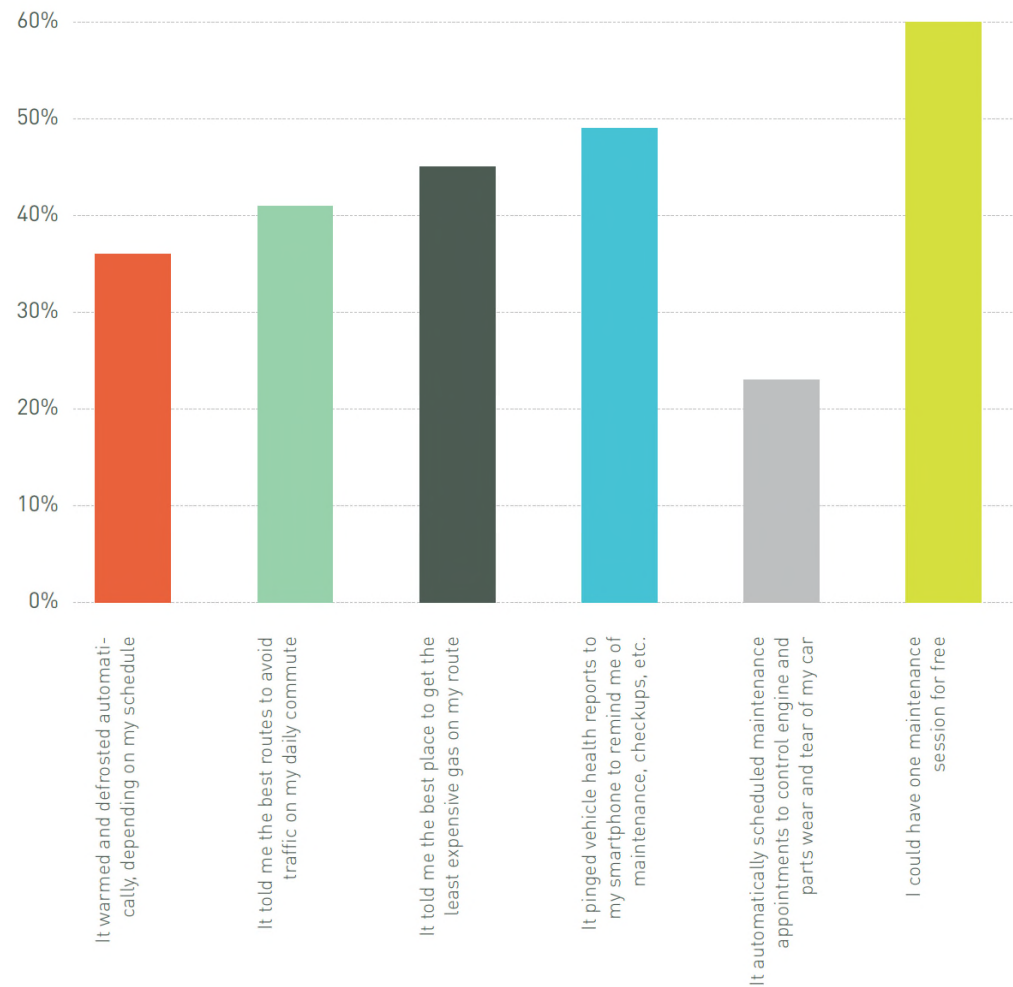
- Would you share data from your car with the manufacturer if
 - It warmed and defrosted automatically depending on your schedule?
 - It told you the best routes to avoid congestion?
 - It told you the best place to get the least expensive gas on your route?
 - It sent vehicle health reports to your smart phone and reminded you of maintenance?
 - It automatically scheduled maintenance appointments?
 - It gave you a free maintenance session a year?

Smart Car Applications

- Why would you buy a car that shares data with the manufacturer?

(Acquity Group, 2014)

I WOULD BE WILLING TO SHARE DATA FROM MY CAR WITH THE CAR'S MANUFACTURER, IF _____.





Autonomous Cars

Morgan Stanley report, 2014:

“[Autonomous cars] are no longer just the realm of science fiction. They are real and will be on roads sooner than you think. Cars with basic autonomous capability are in showrooms today, semi-autonomous cars are coming in 12-18 months, and completely autonomous cars are set to be available before the end of the decade.”

The First Semi-autonomous Cars

2015 Infiniti Q50S



AMG2016 BMW 750i xDrive



2015 Tesla Model S P85D



2015 Mercedes-Benz S65 AMG



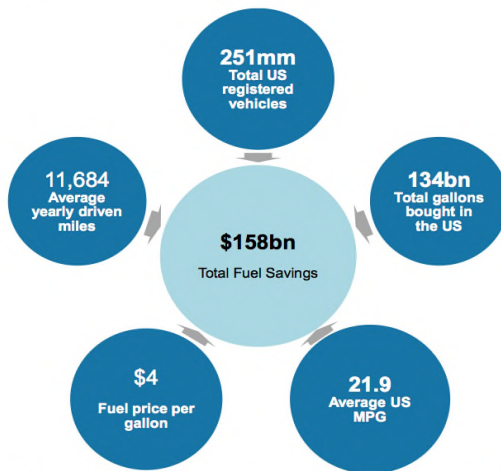
Autonomous Cars

Morgan Stanley report, 2014:

- Fuel savings
- Reduction in accident costs
- Productivity gains

Total Dollar Spent on Fuel (2012)

US data

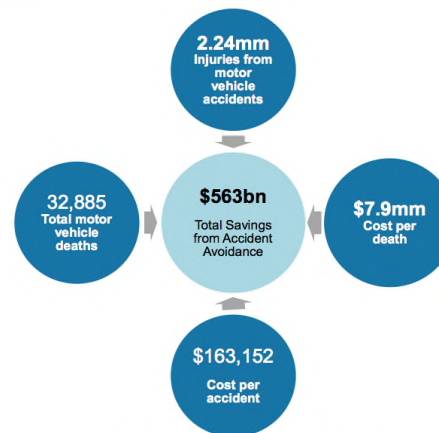


Source: US Department of Transportation, Federal Highway Administration, Morgan Stanley Research

Estimated Fuel Savings (Assuming 30% increase in efficiency)

Cost of Motor Vehicles-related Fatal and Non-fatal Injuries

US data

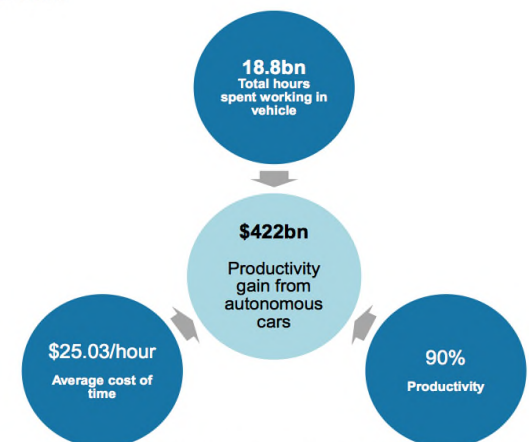


Source: US Department of Transportation, National Highway Traffic Safety Administration, Federal Highway Administration, EPA, FDA, AAA, Morgan Stanley Research

Estimated Accident Cost Savings (Assuming elimination of driver error)

Productivity Gain from Autonomous Cars

US data



Source: Census, Federal Highway Administration, Morgan Stanley Research

Estimated Productivity Gain

(Early) Smart Home Devices

Top 7 by Fortune Magazine (2014)



Security Alarm



Smart Slow-cooker



Connected Smoke Detector



Smart Air Conditioner



Weather-based Sprinkler Controller



Remote Temperature Controller



Water Leak Detector

Top Smart Home Device of 2016 (CNet)

- <https://www.cnet.com/topics/smart-home/best-smart-home-devices/>

amazon echo

Always ready, connected, and fast. **Just ask.**





Today's Top Categories

(PC Magazine, 2018)

- Hubs and controllers: Amazon Echo, Echo Dot, Google Home, etc
- Surveillance cameras
- Locks and home security systems
- Smart heating and cooling
- Smart lighting
- Smart cookware
- Cleaning
- Health and fitness (a BIG category)



Smart Home Devices

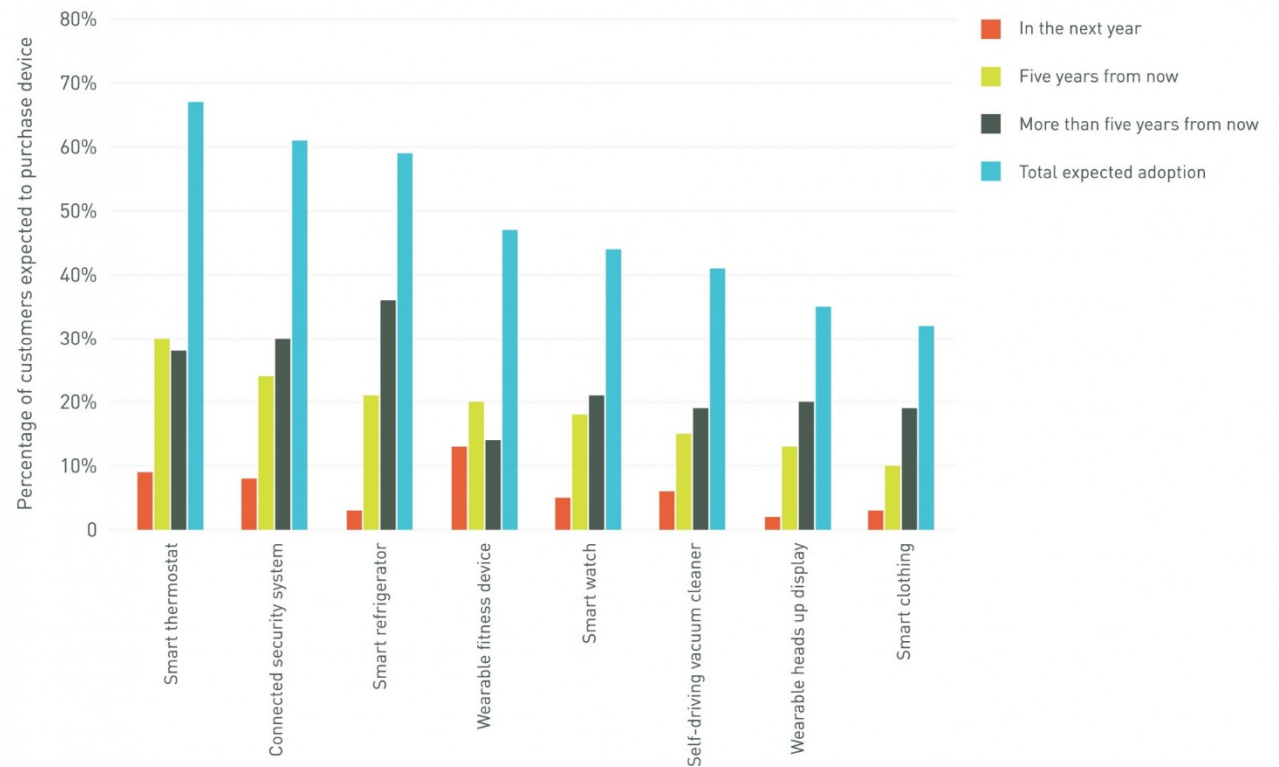
- In the next 5 years, would you purchase:
 - A smart thermostat?
 - A smart refrigerator?
 - A wearable fitness device?
 - A smart watch?
 - A self-driving vacuum cleaner?
 - A wearable head-mounted display?
 - An item of smart clothing?

Smart Home Devices

- Percentage of consumers projected to buy some connected home device in the near future

(Acquity Group, 2014)

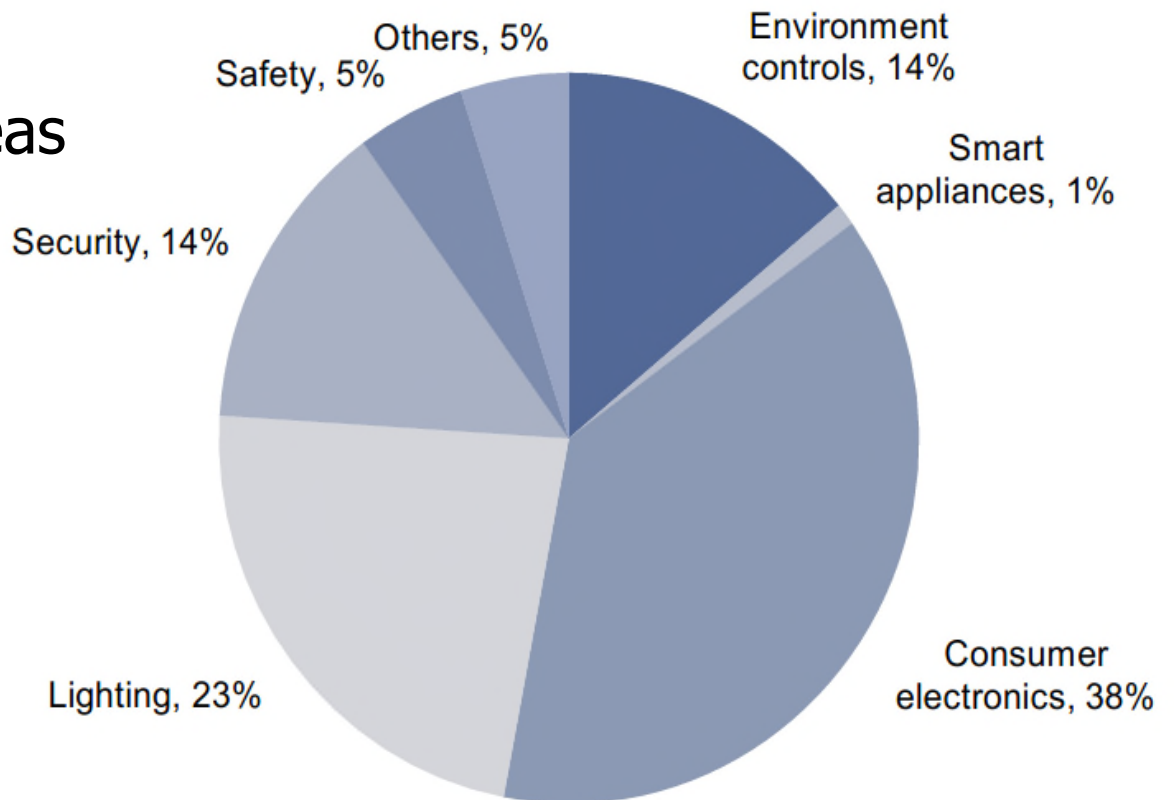
PROJECTED NEW ADOPTION OF CONNECTED TECHNOLOGY BY CONSUMERS



Smart Home Markets

- Revenue projections from different smart home application areas

(Goldman Sachs, 2015)

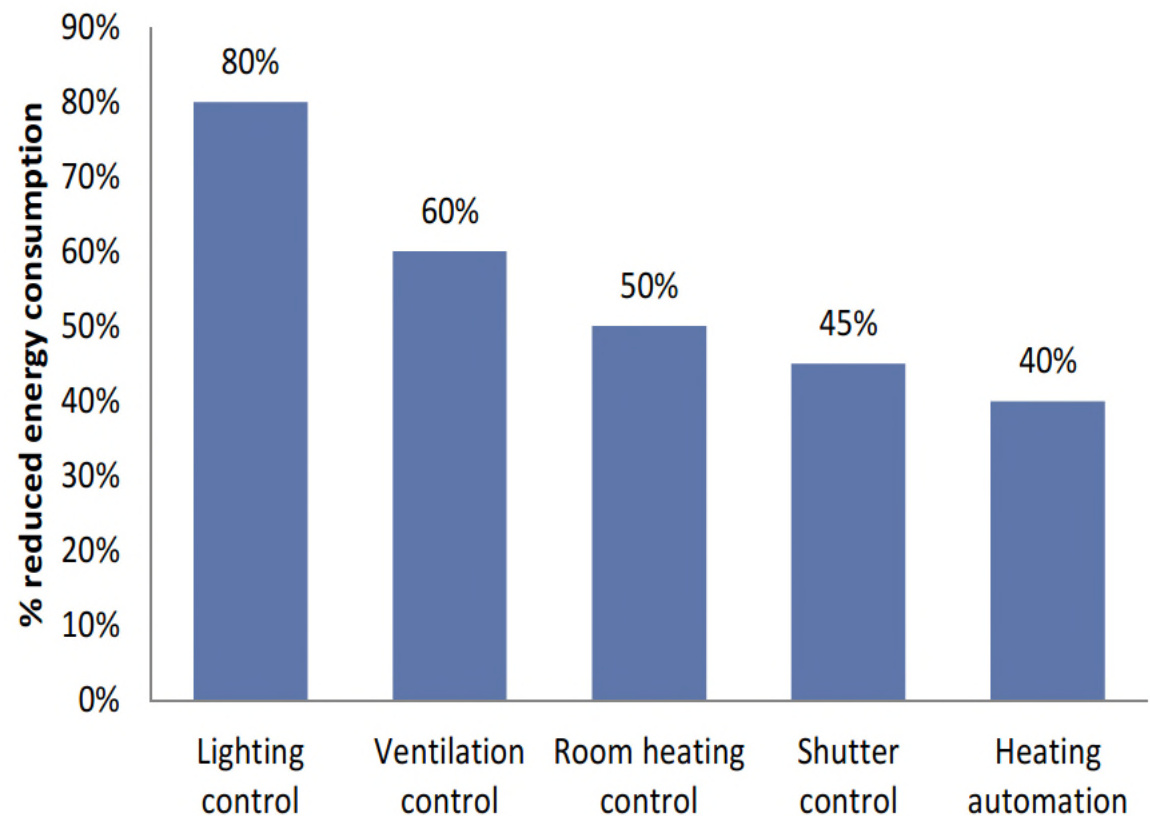


Home automation market - North America

Example: Building Energy Savings

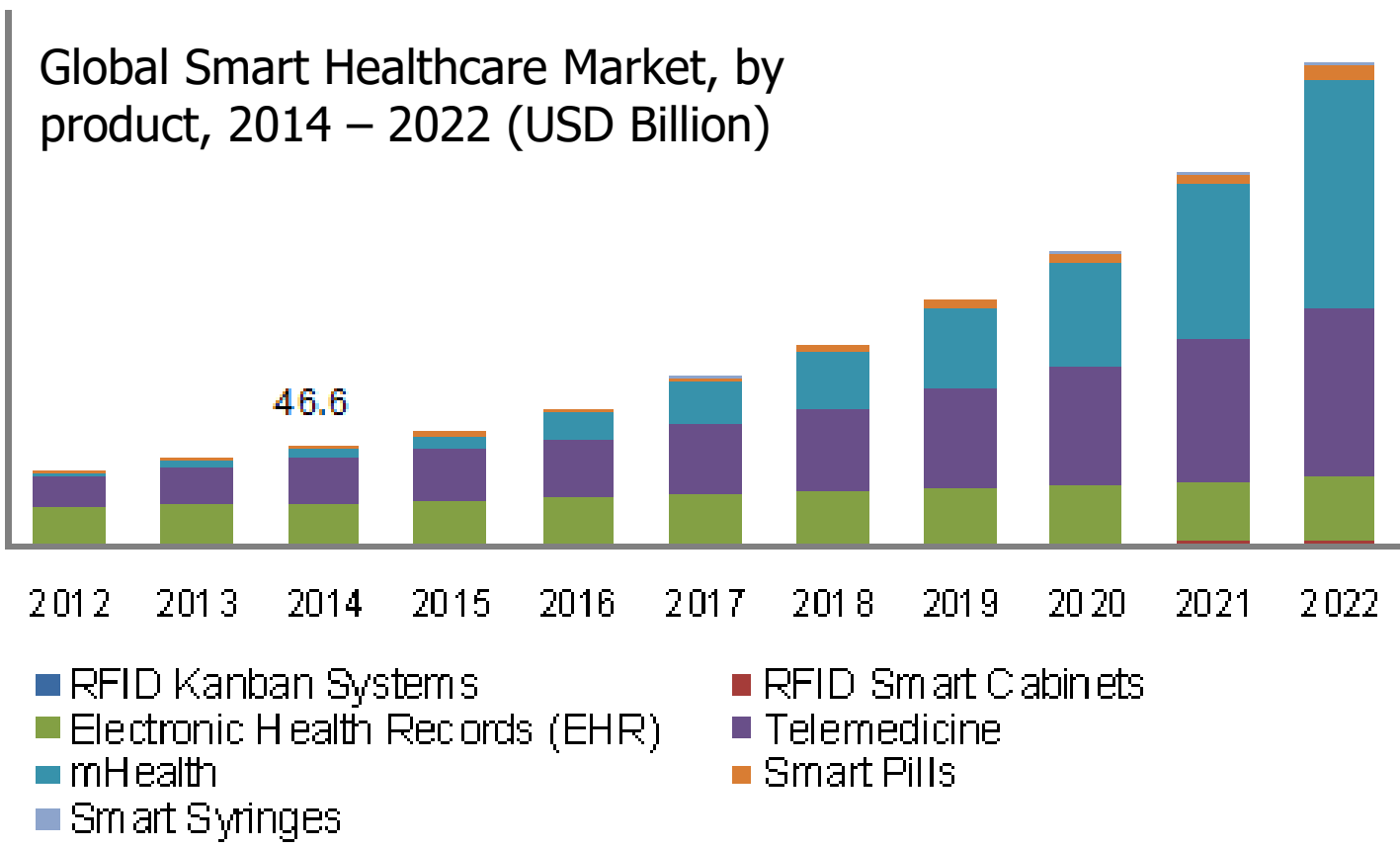
- Significant savings are expected thanks to sensing and automation

(Goldman Sachs)



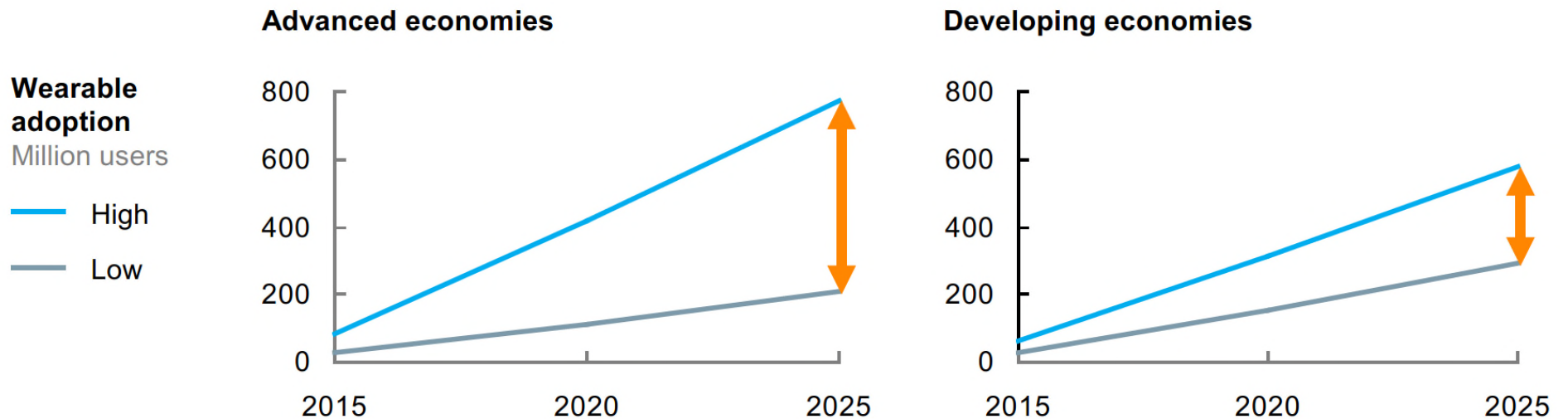
Health and Wellness

■ Healthcare products



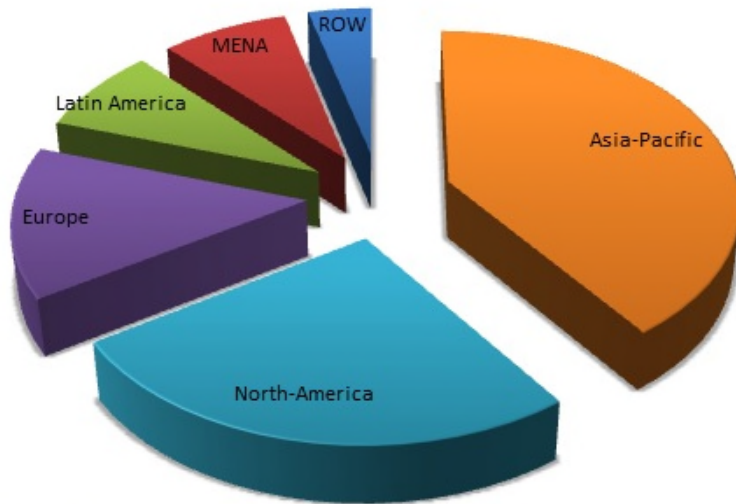
Health and Wellness

- Adoption of wearable health and wellness products (McKinsey)



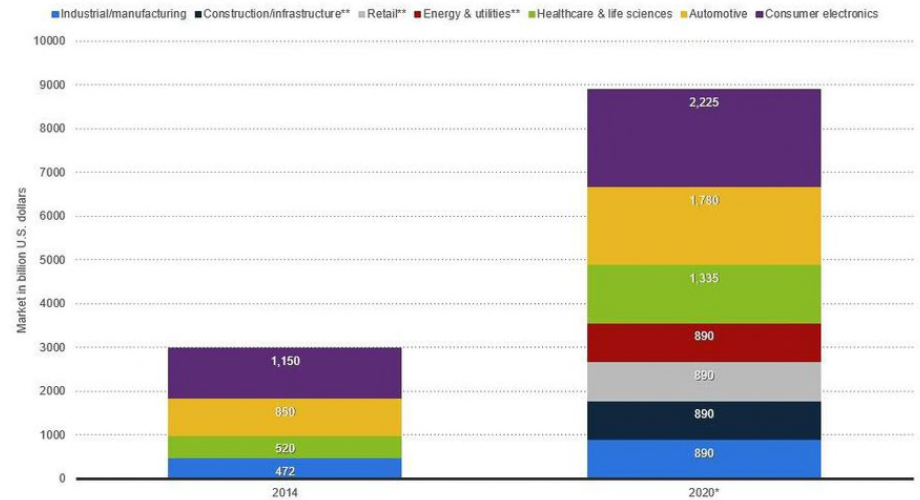
IoT Revenue

Global Internet of Things (IoT) Market Revenue Share (%), 2015



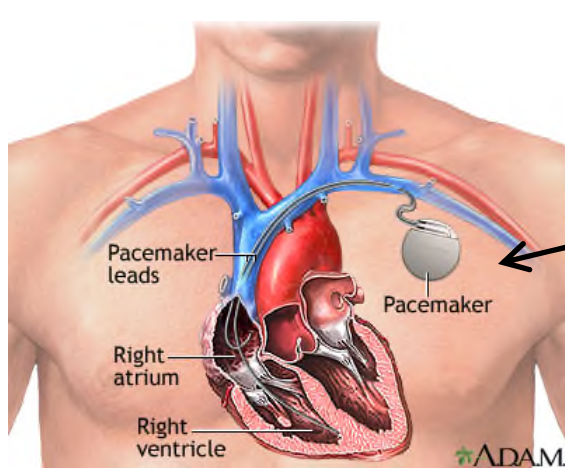
Source: Research Nester

Size of the Internet of Things market worldwide in 2014 and 2020, by industry (in billion U.S. dollars)



Security in Personal and Implantable Devices

- Online murder?



Security in Personal and Implantable Devices

- Former US Vice President disables wireless on his pacemaker

Doctors disabled wireless in Dick Cheney's pacemaker to thwart hacking

by [Lisa Vaas](#) on October 22, 2013 | [1 Comment](#)

FILED UNDER: [Celebrities](#), [Data loss](#), [Denial of Service](#), [Featured](#), [Malware](#), [Security threats](#), [Vulnerability](#)

Former US Vice President Dick Cheney's doctors disabled his pacemaker's wireless capabilities to thwart possible assassination attempts, he said in an interview with [CBS's "60 Minutes"](#) that aired on Sunday.

Cheney's heart problems were bad: between 1978 and 2010, he suffered five heart attacks, underwent quadruple bypass surgery, and had a pump implanted directly to his heart. A defibrillator was implanted to regulate his heartbeat in 2007.

Cheney told his 60 Minutes interviewer, CNN Chief Medical Correspondent Dr. Sanjay Gupta, that at the time of the pacemaker implant, he was concerned about reports that attackers could hack the devices and kill their owners:





Challenges?

■ ...



Challenges?

- Massive scale
- Architecture/interactions/dependencies
- Big data analytics
- Robustness/entropy
- Openness
- Security
- Privacy
- Humans in the loop