# Actualization of IoT:
# Environmental, Sustainability & Infrastructure

*Enabling sustainable solutions for the global environment through novel sensing*

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Planet Singular

April 17, 2017

# Overview & Key themes

- ***Challenges***: natural resources/sustainability, regulatory & technical complexity, disparate population growth, research funding, technology development/ramp pitfalls, infrastructure gaps, lack of long term visioning, insufficient systems integration
- ***TSensor opportunities***: there is a strong foundation of institutions (ICAMR, MIST, MEMS, SEMI, SRC ERC, Leti, imec, Fraunhofer), industry (GE Research, Intel Labs, etc), government, academic and foundational efforts underway
- ***Proven strategies:*** lessons from the historic semiconductor industry technology life cycle systems can provide direction and collaborative focus for the actualization process!
- ***Potential application***: apply learnings to water management: it's about creating new business opportunities, mitigating risk, stakeholder management, collaboratively defining long term technical and strategic goals and systems integration

# SUMMARY

—‘TSensor’ concept of ubiquitous sensing is essential in understanding/managing complex environmental systems (but not all sensors are created equal!)

—Semiconductor industry-developed strategies can provide an effective path to the actualization of IoT

— Environmental (& related) challenges can no longer be solved by a standalone project or driven by a single entity

—Ubiquitous sensing, ‘big data’, analytics, IT, hardware and software technologies are tools, not solutions

—Focus on the ‘end in mind’ (problem being solved, how is the work helping people and/or their communities)

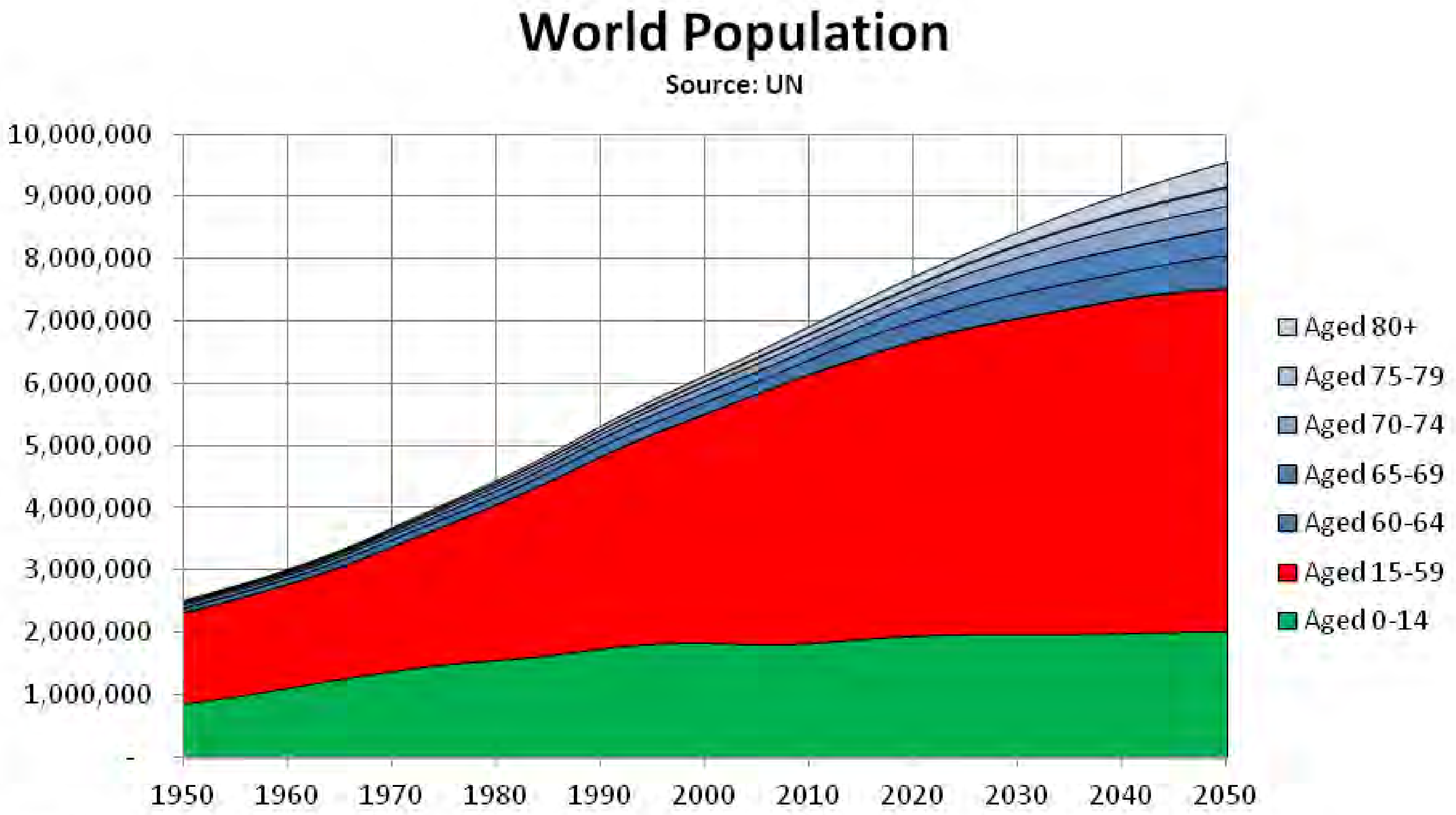
—Biggest hurdle is scale up (development), not tech or $

# Path for action

1. Select a ‘regional’ challenge (water, air, solid waste)
2. Identify key stakeholders (academic, community groups, foundations, non profits, local industry and government)
3. Establish a public-private partnership to create, drive and implement a  technology roadmap, long term goals, framework , strategies, processes, implementation projects
4. Secure independent funding to ensure objective independence, working with state/regional government on behalf of the common good
5. Connect long term strategic goals, technology development and scale up to drive working IoT based solutions (emphasize system integration, proactive stakeholder engagement, jobs and training & community participation)

# Back-up from here

# Population complexity



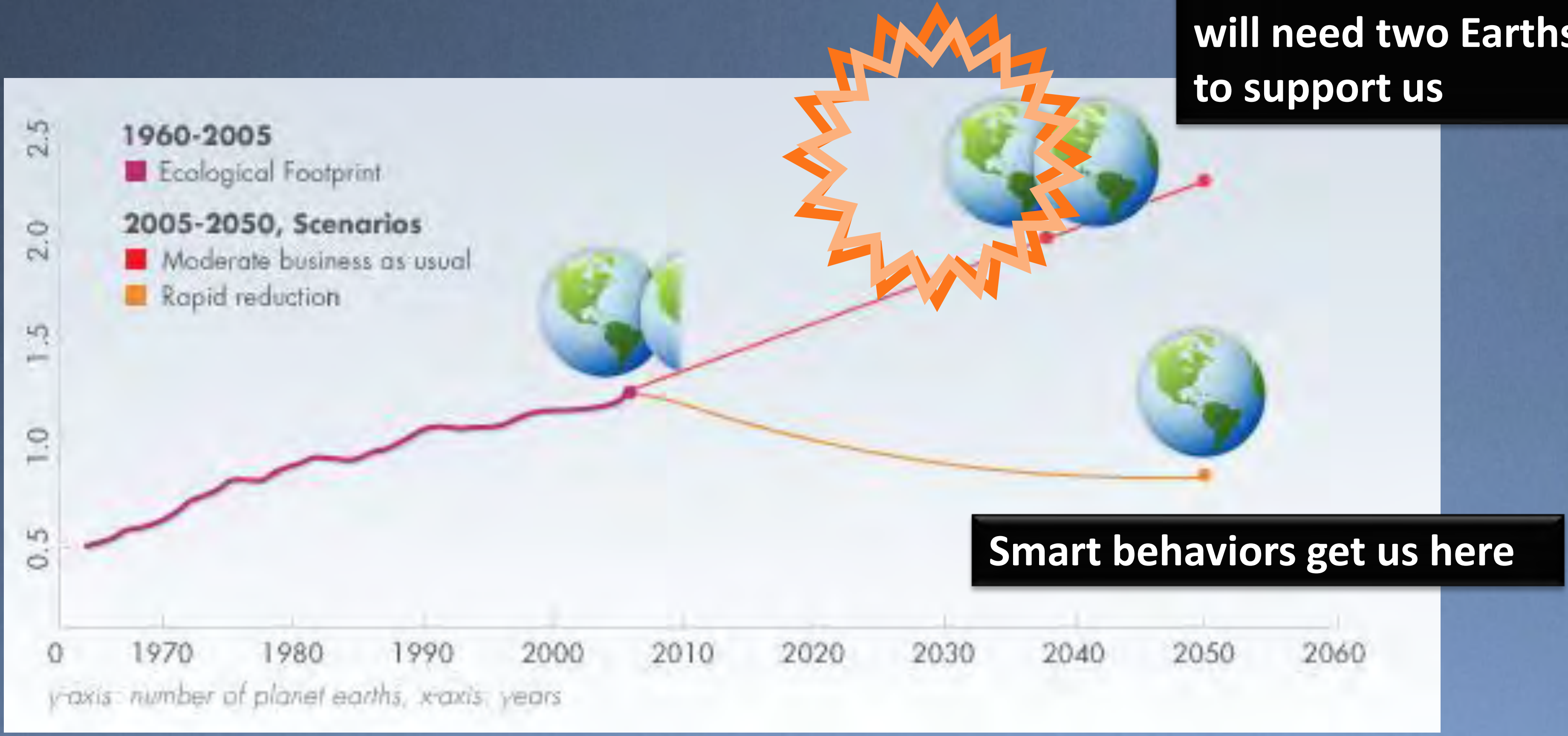
World Population

Source: UN

| | 1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Above 60** | 8% | 8% | 8% | 9% | 9% | 10% | 11% | 13% | 16% | 19% | 21% |
| **Below 15** | 34% | 37% | 38% | 35% | 33% | 30% | 27% | 25% | 24% | 22% | 21% |

Graphic:: deconstructingrisk.com

# YOU NEED A SMART SOCIETY TO HAVE A SUSTAINABLE SOCIETY



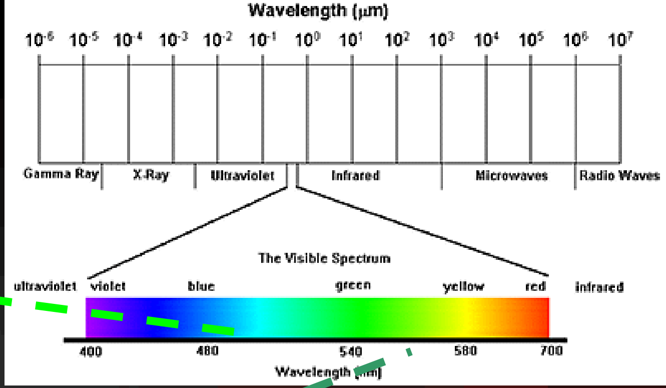
**If consumption trends continue, we will need two Earths to support us**

**Smart behaviors get us here**

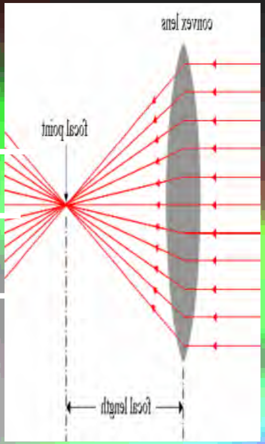
7.5 billion people today
1.3 billion have no safe drinking water
2.6 billion have no sanitary conditions
9+ billion people by 2050

**Source: Global Footprint Network**

# *The ‘spectrum’ of green definitions*



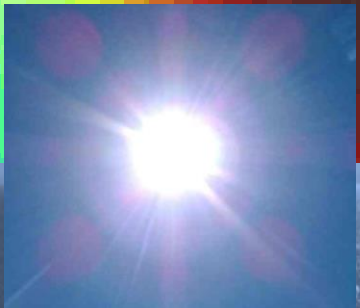
External dispersion of green



- ✓ **Sustainability**
- ✓ **E/H/S**
- ✓ **Circular Economy**
- ✓ **Fair labor practices**
- ✓ **Social Responsibility**
- ✓ **Natural Resource Management**
- ✓ **Legislation, Regulation, Permits**
- ✓ **Technology Development**
- ✓ **Governance**
- ✓ **Materials design/replacement**

**CHALLENGES**

- Wide spectrum of green definitions, ambiguity
- Narrow focused efforts
- Project/program based (tactical scope)
- Lack of strategic planning
- Insufficient coordination
- Complex environment, rapid technology changes
- Degraded social IQ (communities, sense of the ‘common good’)



# What has changed in the ‘environment’?

*From the late ‘60’s….*

**Industry**

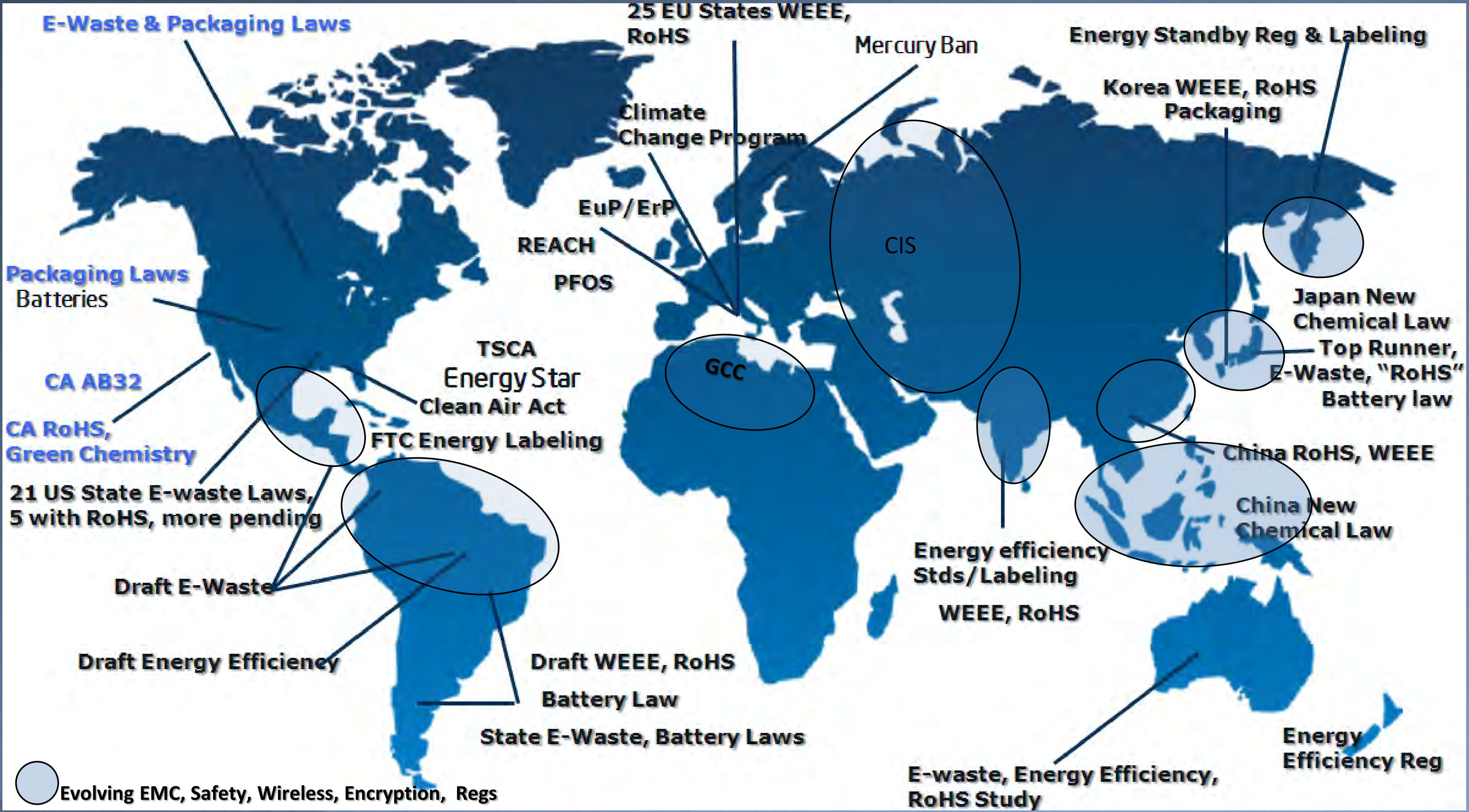
*Community, site impacts………….natural resource usage…………..global issues*

# To our current reality….

Raw material → Sub Supplier → Direct Supplier → Industry → Industry customer → End Customer

*Community, site impacts………….natural resource usage………….global issues*

# Global Regulatory Complexity



E-Waste & Packaging Laws

25 EU States WEEE, RoHS

Mercury Ban

Energy Standby Reg & Labeling

Korea WEEE, RoHS Packaging

Climate Change Program

EuP/ErP

REACH

PFOS

CIS

Packaging Laws
Batteries

Japan New Chemical Law

Top Runner, E-Waste, "RoHS" Battery law

TSCA
Energy Star
Clean Air Act

GCC

CA AB32

CA RoHS,
Green Chemistry

FTC Energy Labeling

China RoHS, WEEE

21 US State E-waste Laws,
5 with RoHS, more pending

China New Chemical Law

Energy efficiency Stds/Labeling

WEEE, RoHS

Draft E-Waste

Draft Energy Efficiency

Draft WEEE, RoHS

Battery Law

State E-Waste, Battery Laws

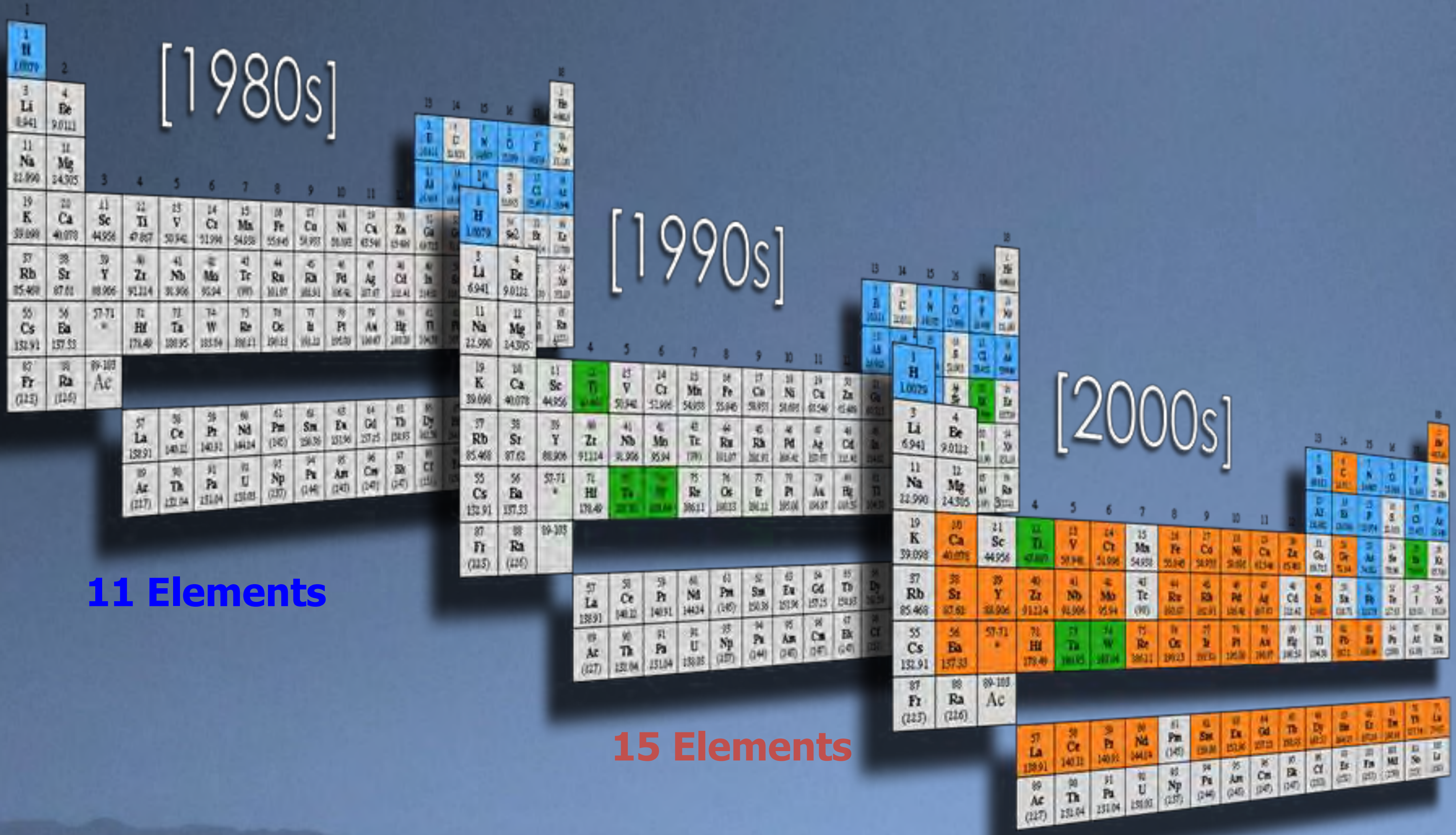
Energy Efficiency Reg

E-waste, Energy Efficiency, RoHS Study

○ Evolving EMC, Safety, Wireless, Encryption, Regs

**Increasing Regulatory Complexity**

# Introduction of New Materials

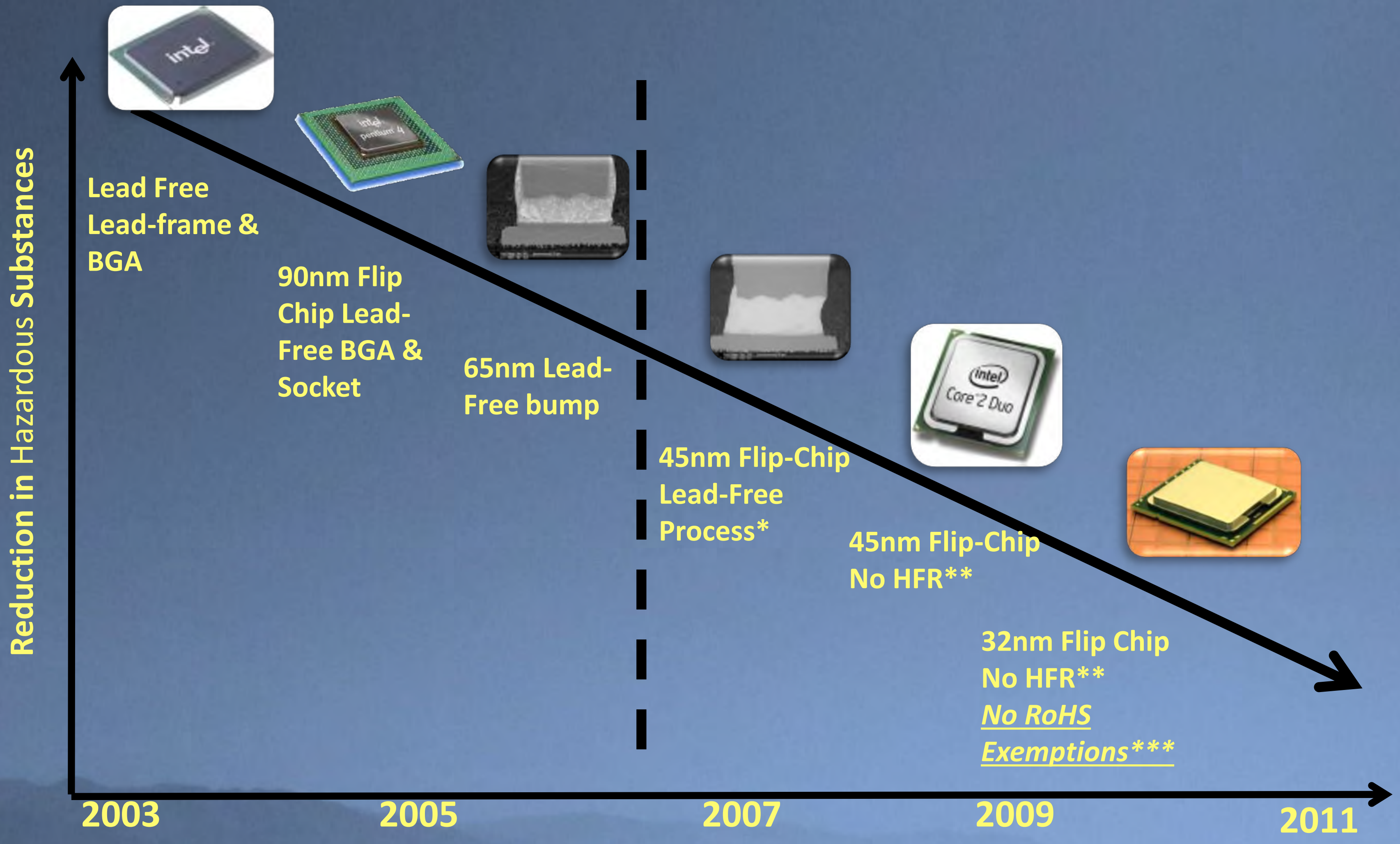


**11 Elements**

**15 Elements**

**>60 Elements**

# Lead-free/Halogen-free



Reduction in Hazardous **Substances**

**Lead Free Lead-frame & BGA**

**90nm Flip Chip Lead-Free BGA & Socket**

**65nm Lead-Free bump**

**45nm Flip-Chip Lead-Free Process***

**45nm Flip-Chip No HFR****

**32nm Flip Chip No HFR****
***No RoHS Exemptions******

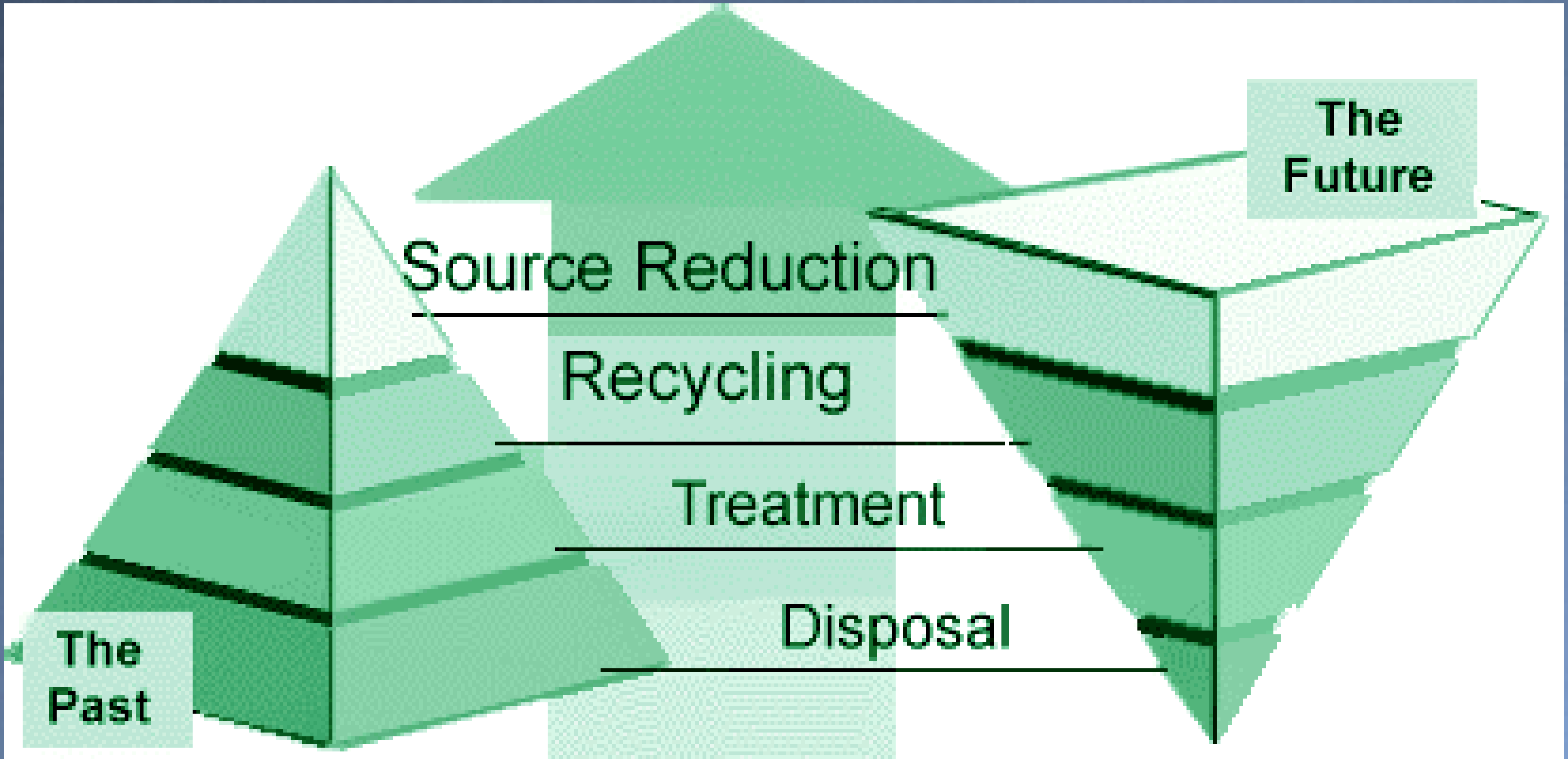
**2003** **2005** **2007** **2009** **2011**

* 45nm product is manufactured on a Lead Free process. Lead-free per EU RoHS directive July, 2006 (2002/95/EC, Annex A). Some EU RoHS exemptions may apply to other components used in the product package.

** 45nm Applies only to halogenated flame retardants & PVC in components. Halogens are below 900 PPM bromine & 900 PPM chlorine.

*** 32nm is manufactured on a Lead Free process. Lead-free per EU RoHS directive July, 2006 (2002/95/EC, Annex A). No Exemptions Required

# Pollution Prevention Hierarchy



# TSensors Vision: Enabling Sustainable Solutions for the Global Environment through Novel Sensing

Toshikazu Nishida, Ph.D.

November 10, 2016

MEMS & Sensors Executive Congress®
US 2016
NOVEMBER 9-11, 2016 • SCOTTSDALE, AZ

MIST
CENTER
Multi-functional Integrated System Technology

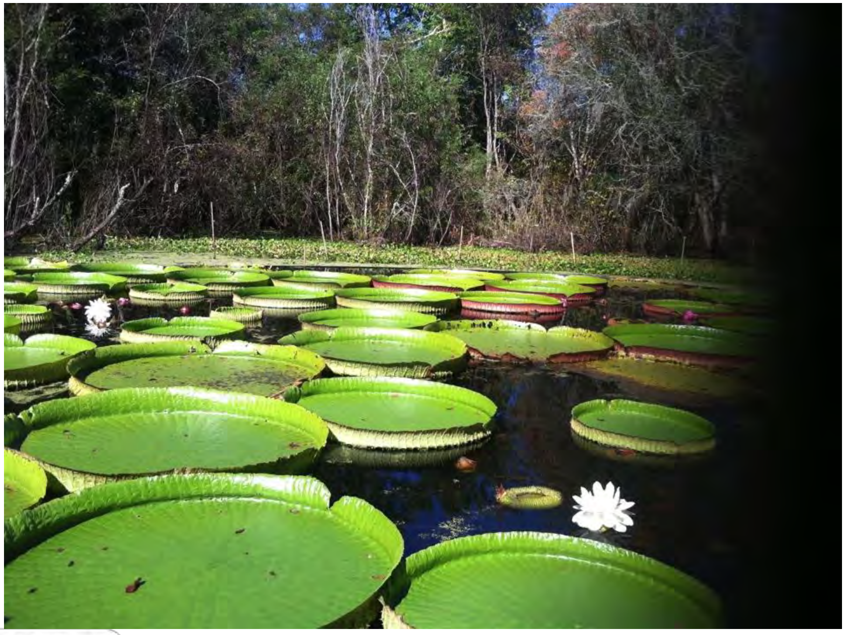
# TSensors Vision Book

- TSensors: Enabling Sustainable Solutions for the Global Environment through Novel Sensing
  - Chapters include White papers Call for Action
    - A Global Problem with Individual, Local, State, and National Consequences
    - Fundamental Monitoring Concepts: Components to Systems
    - Chemical Pollution Sensing
    - Biological Pollution Sensing
    - Particulate Pollution Sensing
    - Radiation Pollution Sensing
    - Detecting Terrorist Threats
    - Beyond Monitoring Technology – Regulatory
    - Scale Up Requirements
    - Next Phase: Challenges = Opportunities

# Future Technology Solutions

- Capturing Value from MEMS and Sensors

- What is the opportunity related to clean environment?



# Breakthrough Energy Coalition

- Premise
  - “The existing system of basic research, clean investment, regulatory frameworks, and subsidies fails to sufficiently mobilize investment in truly transformative energy solutions for the future.”
- Challenge
  - Span valley of death between basic research (public) and scaleable clean energy product (private)
- Approach
  - Implement mechanism to analyze basic research results and invest (early, broadly, wisely)

http://www.breakthroughenergycoalition.com/en/index.html

# Pollution Monitoring – Challenging Sensor Problem

| CAS | Chemical |
|---|---|
| 71751-41-2 | Abamectin [Avermectin B1] |
| 30560-19-1 | Acephate (Acetylphosphoramidothioic acid O,S-dimethyl ester) |
| 75-07-0 | Acetaldehyde |
| 60-35-5 | Acetamide |
| 75-05-8 | Acetonitrile |
| 98-86-2 | Acetophenone |
| 53-96-3 | 2-Acetylaminofluorene |
| 107-18-6 | Allyl alcohol |
| 107-11-9 | Allylamine |
| 107-05-1 | Allyl chloride |
| 7429-90-5 | Aluminum (fume or dust) |
| 20859-73-8 | Aluminum phosphide |
| 1344-28-1 | Aluminum oxide (fibrous forms) |
| 834-12-8 | Ametryn (N-Ethyl-N=-(1-methylethyl)-6-(methylthio)-1,3,5,-triazine-2,4-diamine) |
| 117-79-3 | 2-Aminoanthraquinone |
| 60-09-3 | 4-Aminoazobenzene |

With so many targets, must define problem and their measurement requirements…

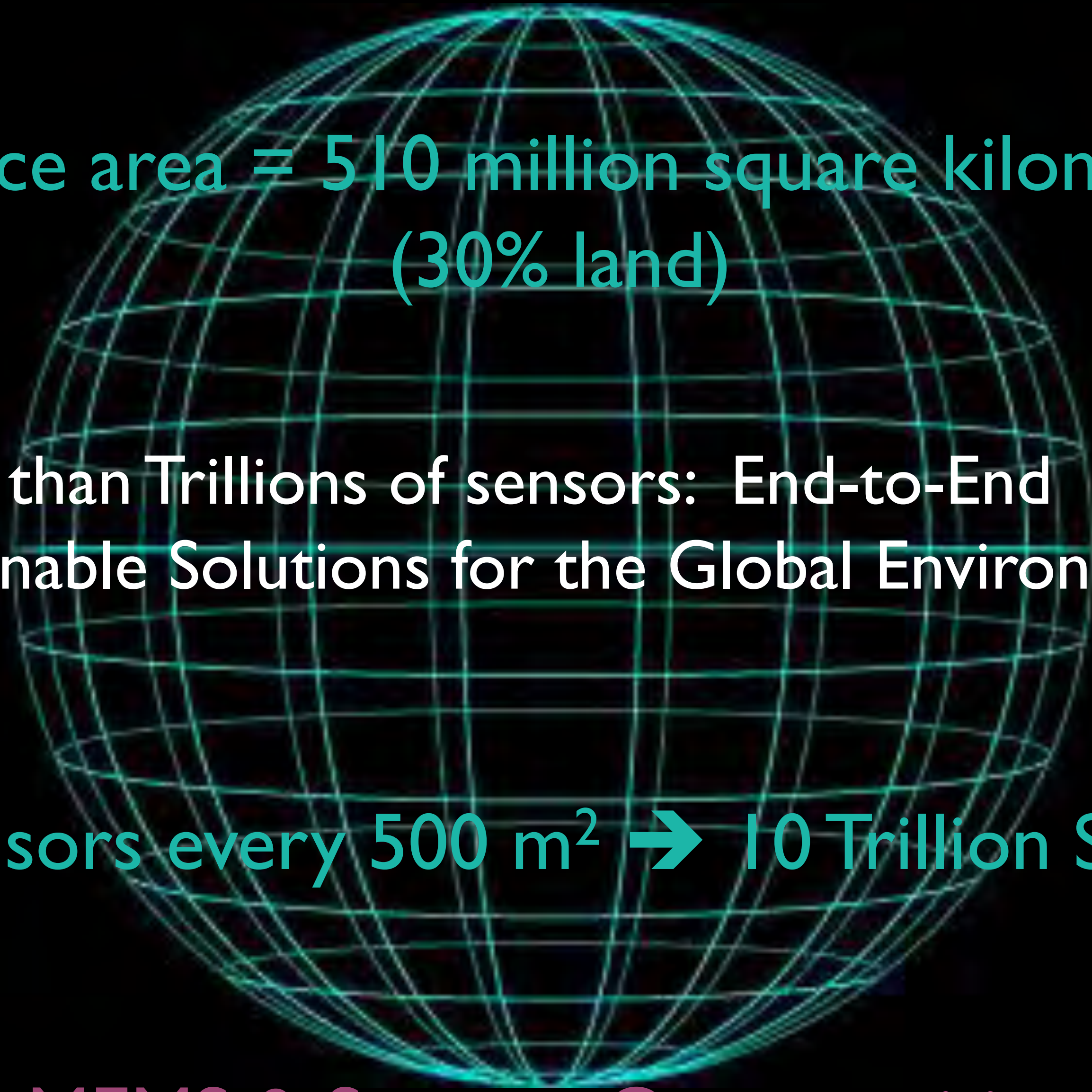
The U.S. Environment Protection Agency currently lists 689 chemicals in the Toxic Release Inventory (TRI) because of their effects on cancer, chronic/acute health, and the environment.

The Clean Water Act established a Priority Pollutant List of 129 chemicals for which analytical test methods exist.

The Clean Air Act established standards for 6 common pollutants. EPA is also working to reduce the emissions of 187 toxic air pollutants.

http://www2.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals
http://www.epa.gov/eg/toxic-and-priority-pollutants-under-clean-water-act

# Global Pollution Monitoring: Trillion Sensors Challenge



Surface area = 510 million square kilometers (30% land)

More than Trillions of sensors: End-to-End Sustainable Solutions for the Global Environment

10 sensors every 500 $m^2$ → 10 Trillion Sensors

MEMS & Sensors Opportunities

# Environmental Sensor Considerations/ Tradeoffs

- High accuracy
- High selectivity
- High sensitivity
- High reliability
- Broad dynamic range
- Low initial & operation cost
- Low power
- Fast response time
- Small size
- Life cycle impact

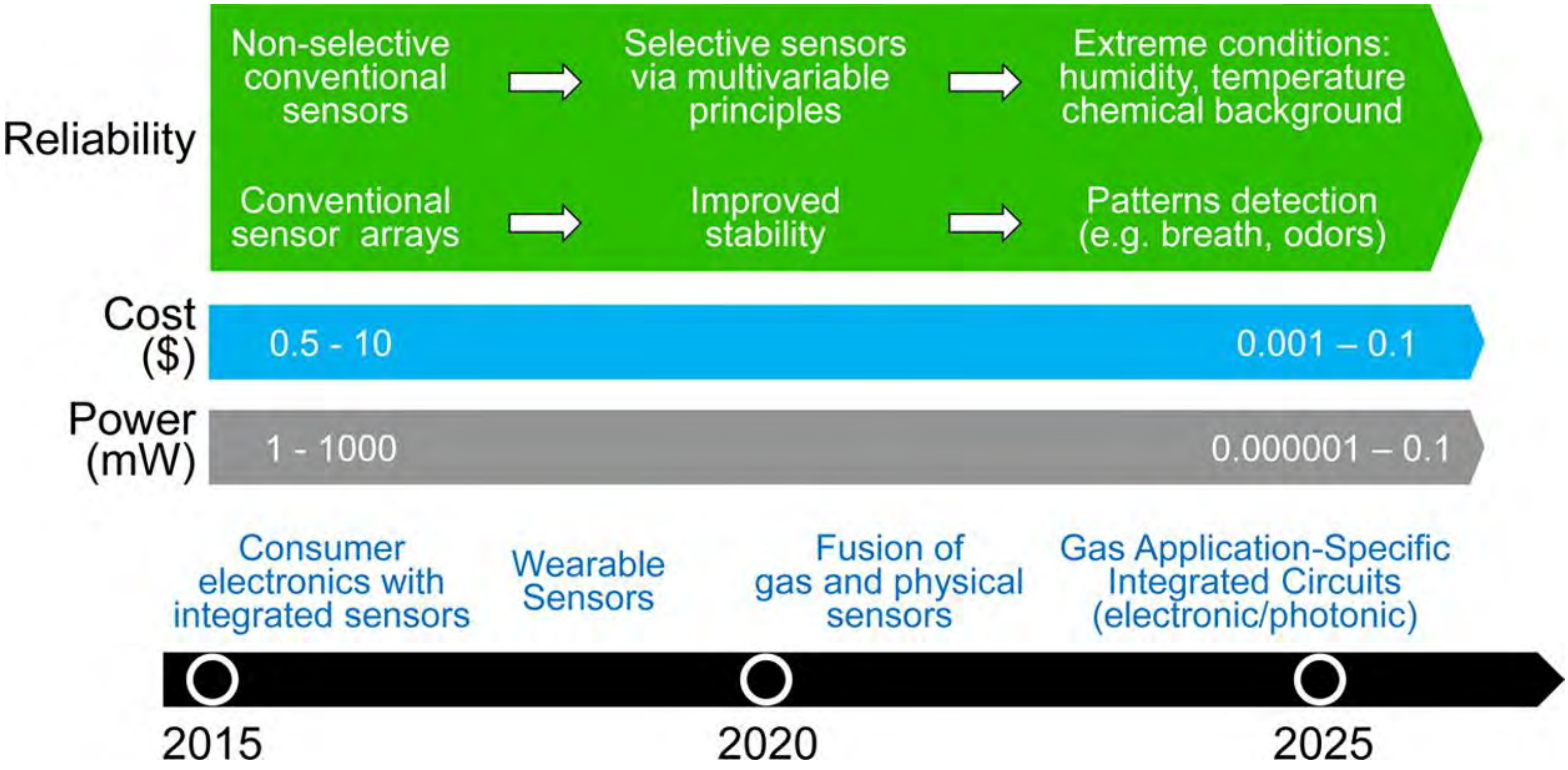
For a viable roadmap for 2025 towards trillion sensors, need exponential technologies

# Current Practices

- Precision laboratory equipment ($$$$)
  - Mass spectrometry, gas chromatograph, etc.
  - EPA defines quantitative monitoring methods for both air and water quality
    - Air: Ambient Monitoring Technology Information Center (AMTIC)
    - Water: Clean Water Act Analytical Methods
- Field handheld instruments for state, local use ($$)
  - Air: Aeroqual, TSI, etc.
  - Water: YSI, Hydrolab, etc.
- Low cost sensors for individual use ($)
  - Air: EPA Air Sensor Guidebook
  - Crowdsourcing: EPA promotes "Citizen Science" to help fill in gaps in environmental monitoring
  - However, the challenges include achieving accurate results, proper assessment, and reliability

Water pollutant monitoring more challenging than air pollutant monitoring.

# 2025 Roadmap for Gas Sensors



Reliability

Non-selective conventional sensors → Selective sensors via multivariable principles → Extreme conditions: humidity, temperature chemical background

Conventional sensor arrays → Improved stability → Patterns detection (e.g. breath, odors)

Cost ($)

0.5 - 10

0.001 – 0.1

Power (mW)

1 - 1000

0.000001 – 0.1

Consumer electronics with integrated sensors

Wearable Sensors

Fusion of gas and physical sensors

Gas Application-Specific Integrated Circuits (electronic/photonic)

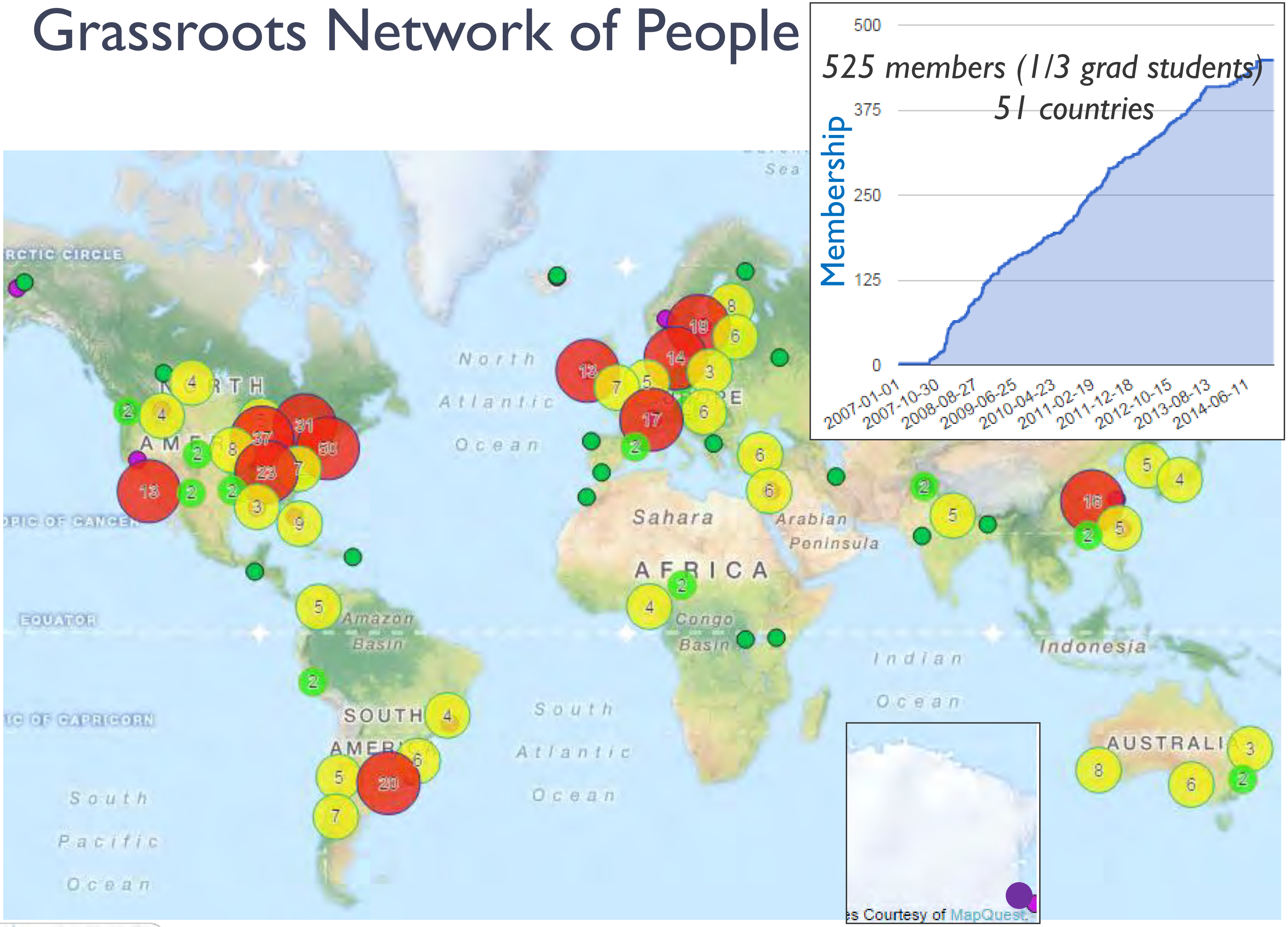
2015

2020

2025

Radislav Potyrailo, Chem. Rev. 116, 11877-11923 (2016)

# Grassroots Network of People



525 members (1/3 grad students)

51 countries

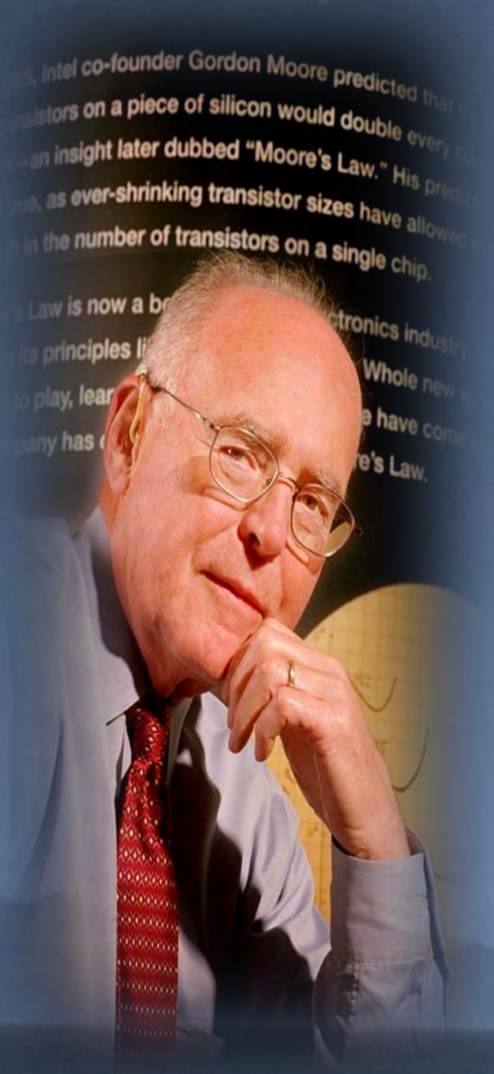
http://gleon.org/members/map

# Semiconductor sustainability strategies

- Manufacturing
  - Design for environment
  - Renewable energy
  - Green Chemistry
  - Energy/water/waste-water management
  - Emissions/flow modeling
  - Systems thinking
- Products
  - Material content
  - Energy
  - C footprint
  - Life Cycle Analysis

- Products in use
  - Sensors
  - SOCs
- Proactive Systems
  - Long range technology roadmap
  - Integrated collaboration
  - Academic, supplier, manufacturing and government partners
  - Sponsored industry R&D

# Microprocessor scaling since ’60’s



## Predictable Silicon Track Record

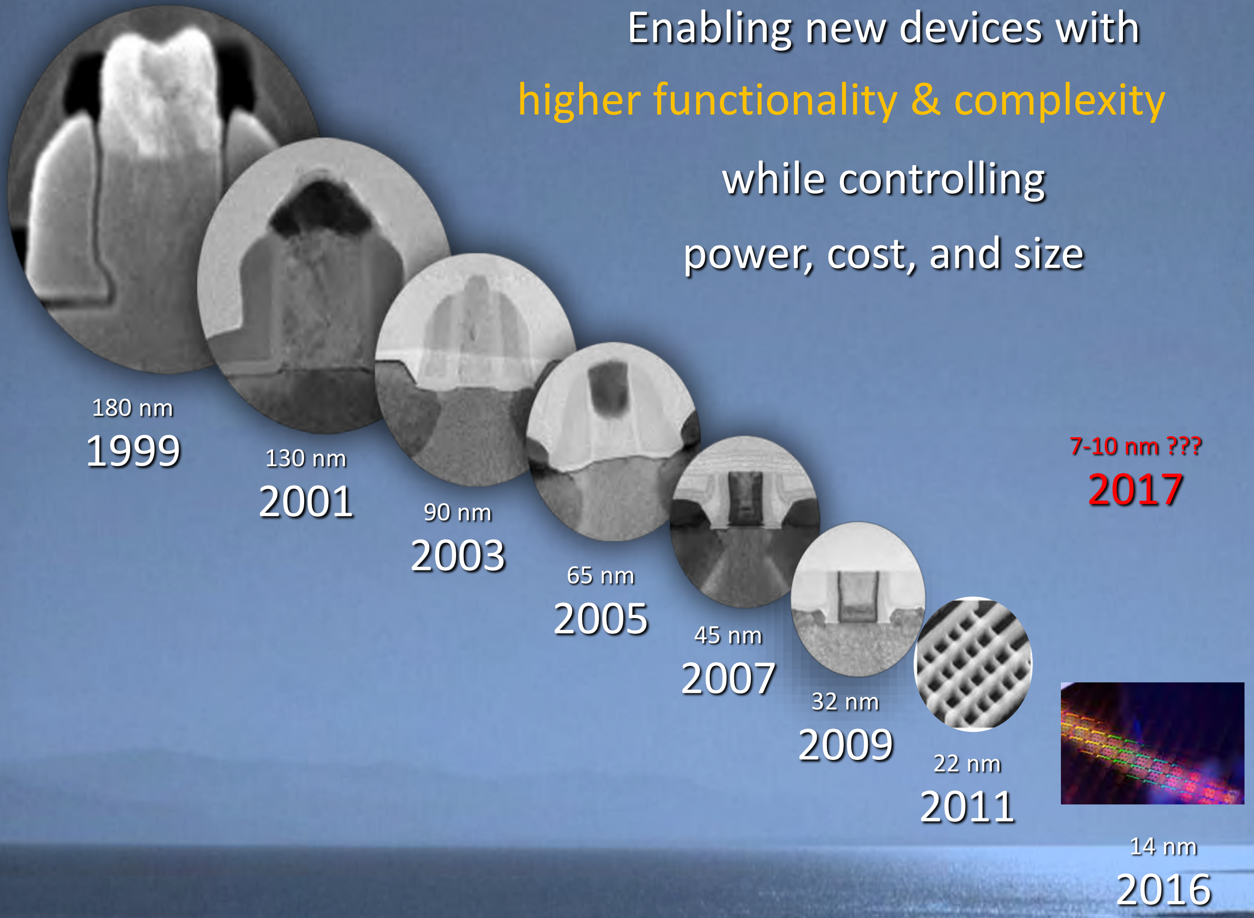
Executing to Moore’s Law

Enabling new devices with

higher functionality & complexity

while controlling

power, cost, and size



Source: Intel

# THE COMPUTE CONTINUUM & THE ENVIRONMENT

Information & Communications Technology is essential to solving environmental problems

# Green Chemistry defined

*The design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances; applicable across the life cycle of a chemical product, including its design, manufacture, and use.*

Application:

*-Green as the preferred (ideal) end state*

*-Create a sustainable framework/process across the technology life cycle*

*-Maximizing the viability of the materials used and addressing ESH mitigation at the outset of chemical design)*

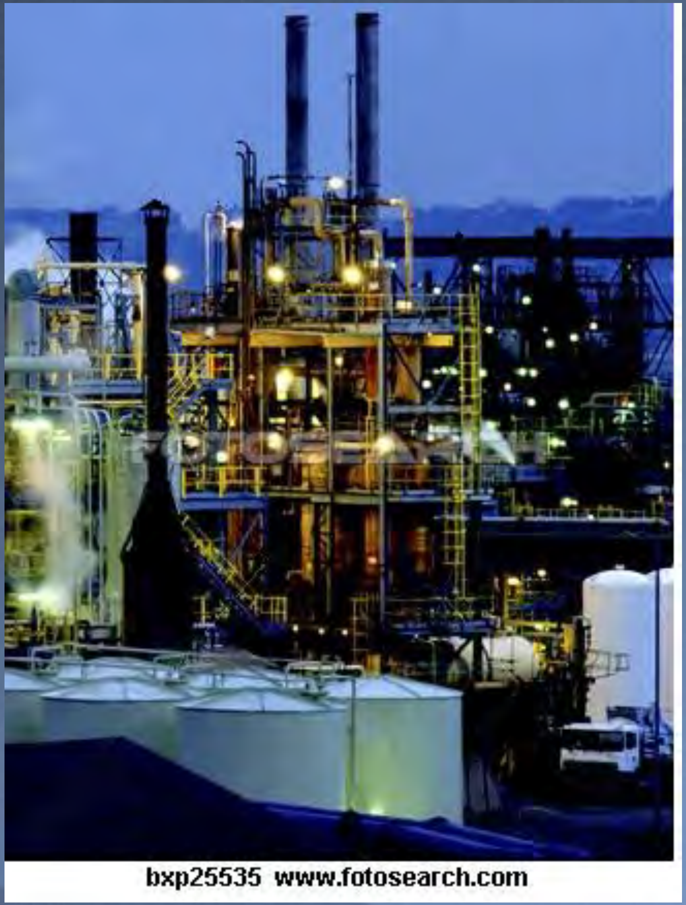
* As defined in text by Warner & Anastas (1998) and used by US EPA , ACS etc

# Green Chemistry Principles

- **Prevention**
  It is better to prevent waste than to treat or clean up waste after it has been created.
- **Atom Economy**
  Synthetic methods should be designed to maximize incorporation of all materials used in process , into the final product.
- **Less Hazardous Chemical Syntheses**
  Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
- **Designing Safer Chemicals**
  Chemical products should be designed to affect their desired function while minimizing their toxicity.
- **Safer Solvents and Auxiliaries**
  The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
- **Design for Energy Efficiency**
  Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
- **Use of Renewable Feedstocks**
  A raw material/feedstock should be renewable rather than depleting whenever technically and economically practicable.
- **Reduce Derivatives**
  Unnecessary derivatization (use of blocking groups, protection/de-protection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, as such steps require additional reagents and can generate waste.
- **Catalysis**
  Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
- **Design for Degradation**
  Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
- **Real-time analysis for Pollution Prevention**
  Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
- **Inherently Safer Chemistry for Accident Prevention**
  Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires

# Green Chemistry

## *The way nature does chemistry*



bxp25535 www.fotosearch.com

*vs.*

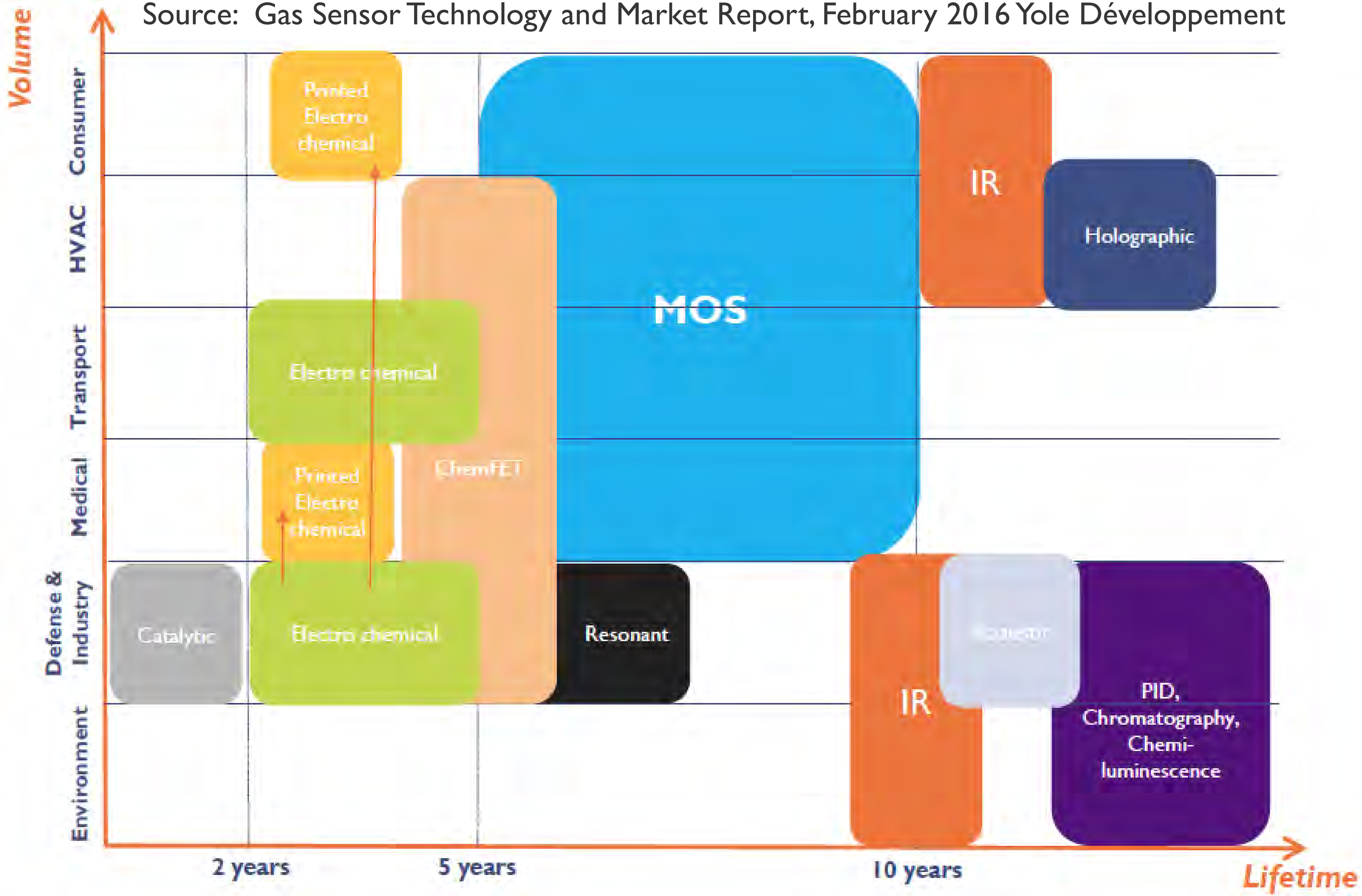
Man
vs
Nature

- **High (low) T**
- **High P**
- **Organic Solvents**
- **Lots of waste**

- **Ambient T**
- **Atmospheric P**
- **Water as solvent**
- **No waste & biodegradation**

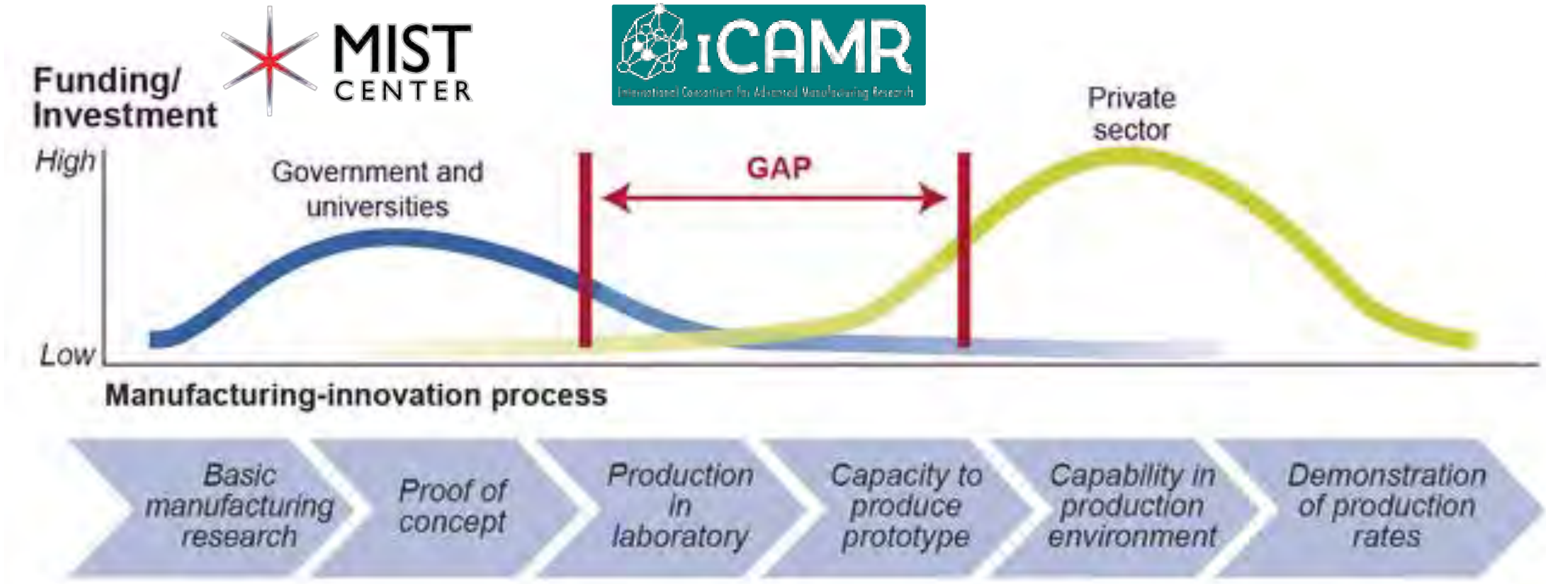
# Chemical Gas Sensor Types

Source: Gas Sensor Technology and Market Report, February 2016 Yole Développement



http://www.i-micronews.com/news/mems/7220-gas-sensors-one-technology-one-application.html

# Challenges for Translation of Early-Stage Technology



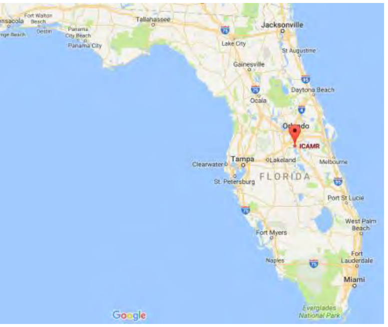
Source: GAO adapted from Executive Office of the President.

http://www.gao.gov/products/GAO-14-181SP

- Role of industry-led consortium to bridge ‘Valley of Death’
- ICAMR is a 501.c.6 industry-led consortium that provides open-innovation platforms that drive high-tech manufacturing

# International Consortium for Advanced Manufacturing Research

- R&D Solutions:
  - New advanced materials on silicon wafer platforms for integration into smart sensors and photonic devices carried out to manufacturable standards
  - ICAMR is a valuable partner for those industries interested in bringing the materials advantages of CNT, graphene, III-Vs, and advanced dielectrics onto the silicon substrate platform for reasons of cost or control capabilities using CMOS technology.



http://icamr.net/solutions.html

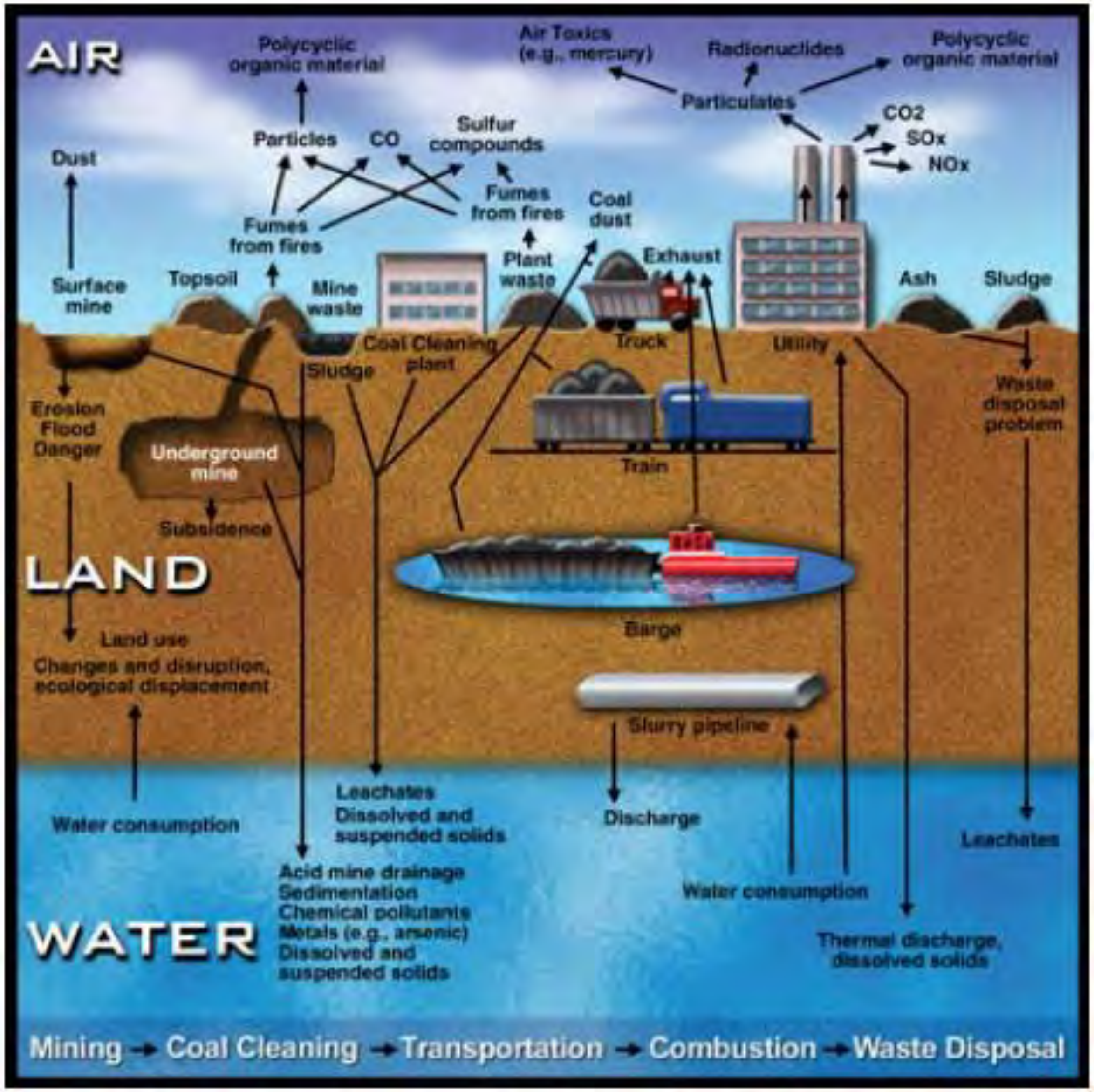
# Paris Climate Agreement

- Historic event
  - Global climate change agreement adopted by 195 countries, kicked into effect on November 4, 2016
- Main goal
  - Limit global warming below +2°C compared to pre-industrial baseline
- How?
  - Curb greenhouse emission excess ‘as soon as possible’
  - Reduce greenhouse emissions to achieve ‘net-zero’ conditions between 2050 and 2100
  - Review progress every 5 years
  - Provide support as needed to help countries adapt and/or adopt renewable energies

# Global Pollution: Air, Water, and Soil

http://www.nature.nps.gov/air/aqbasics/sources.cfm
http://www.filterwater.com/t-articles.waterpollution.aspx

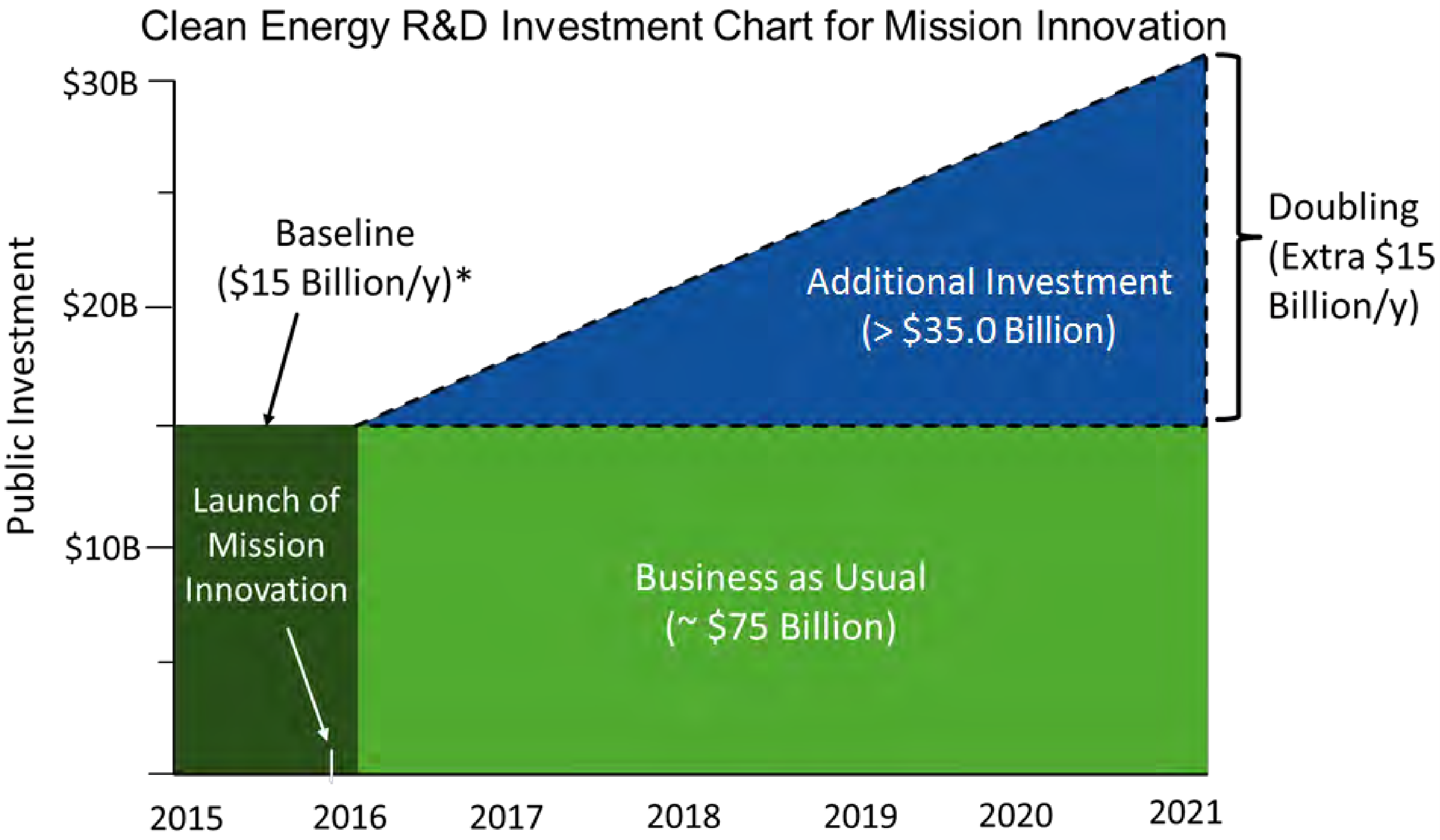
# Pollutants from Coal-Fired Power Plants



| | Projected 2010(Tons) Emissions |
|---|---|
| | 8,600,000 |
| | 3,900,000 |
| | 273,000 |
| | 71 |
| | 8.2 |
| | 3.8 |
| | 78 |
| | 155,000 |
| | 27,500 |
| | 87 |
| | 219 |
| Mercury | 60 |

Source: "Cradle to Grave: The Environmental Impacts of Coal", Clean Air Task Force, 77 Summer Street, Boston, MA June 2001.

# Clean Energy R&D Investment Plan



| Baseline | In US M$ |
|---|---|
| United States | 6415 |
| China | 3800 |
| European Union | 989 |
| Germany | 506 |
| France | 494 |
| S. Korea | 490 |
| Japan | 410 |
| Canada | 295 |
| United Kingdom | 290 |
| Italy | 250 |
| Brazil | 150 |
| Norway | 140 |
| Australia | 78 |
| Saudia Arabia | 75 |
| India | 72 |
| Denmark | 45 |
| Mexico | 21 |
| Indonesia | 17 |
| Sweden | 17 |
| UAE | 10 |
| Chile | 4 |

http://mission-innovation.net/baseline-and-doubling-plans/

# Acknowledgments

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- Dr. Ankineedu Velaga, ICAMR

MIST CENTER

*Innovating More than Moore technologies for smart systems in the Internet of Things era.*

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