IRDS Environmental, Safety, Health and Sustainability (ESH/S) Roadmap: initiative update

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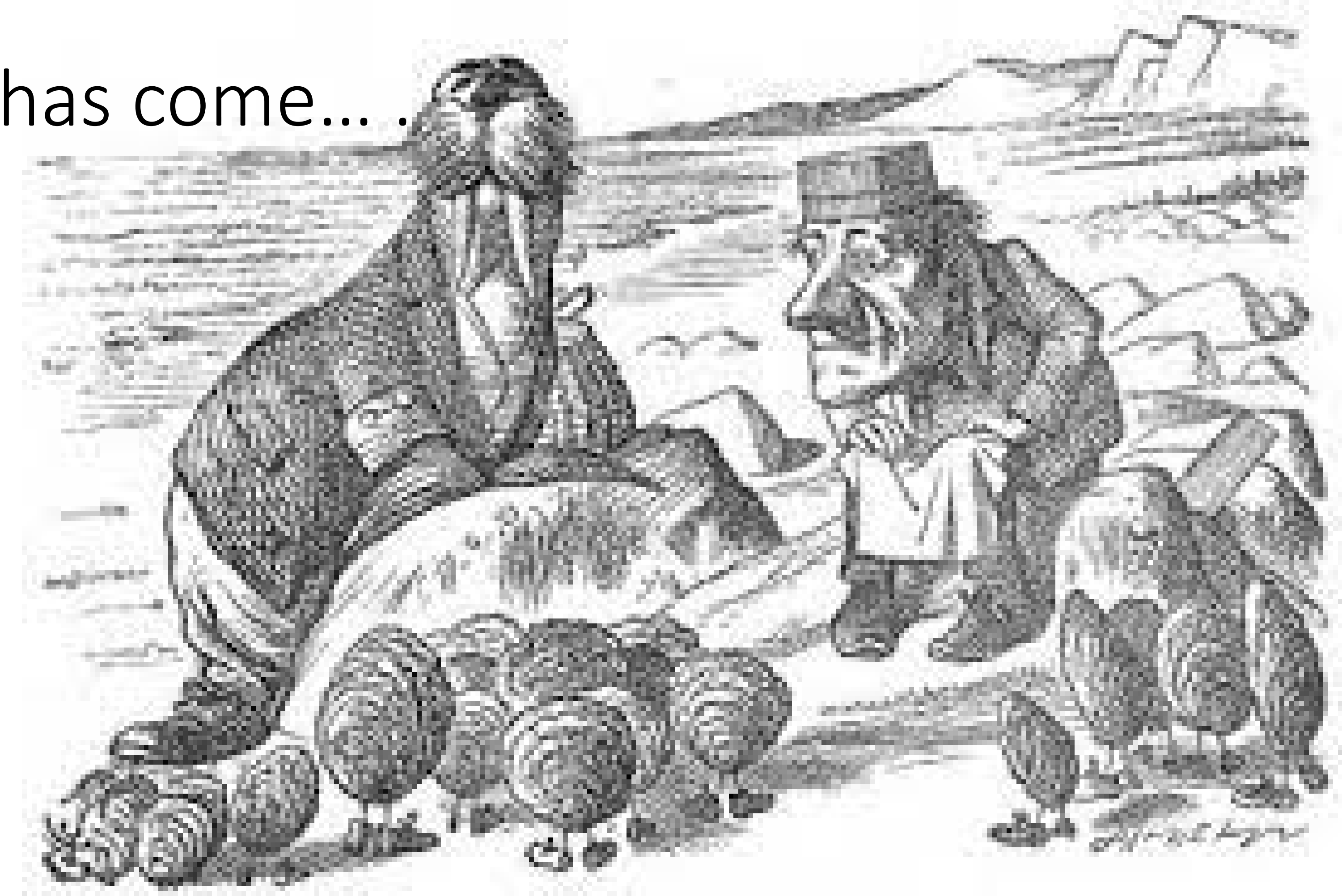
The time has come… .



Key messages

1. The semiconductor technology roadmap process is critical to drive an integrated, technical path forward for ESH/S
2. Inherent EU strengths (academic, government, industry, systems) are uniquely positioned to lead this effort
3. Specifically, the EU academic of industry sponsored research can address gaps in ESH/S technology development (scale up), delivering working solutions for semiconductor manufacturers
4. Workforce development (research and education), especially in ESH/S Technology development must be a priority
5. The industry must change the paradigm from reactively addressing ESH/S issues to work for the environment!

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Agenda

- Technology Roadmap (RM) Overview
- External Landscape (drivers and issues)
- IFT ESH/S Technology Roadmap Overview
  - Team Structure
  - Team org representation
  - Difficult challenges
  - Lithography ESH/S challenges
  - Environmental Sustainability (water/energy) for semiconductor facilities
- Proactive technical development strategies
- Conclusions

IRDS Description

- Continues the evolution of "roadmapping" a projection of semiconductor device research from the International Technology Roadmap for Semiconductors (NTRS→ITRS→IRDS) and development technology and includes the analysis and forecast of system applications and architectures.
- International contributions include those of Europe (SiNANO) and Japan (SDRJ)
  - MOUs are signed by all parties.
  - Observers are with associations in Taiwan (TSIA) and Korea (KSIA).

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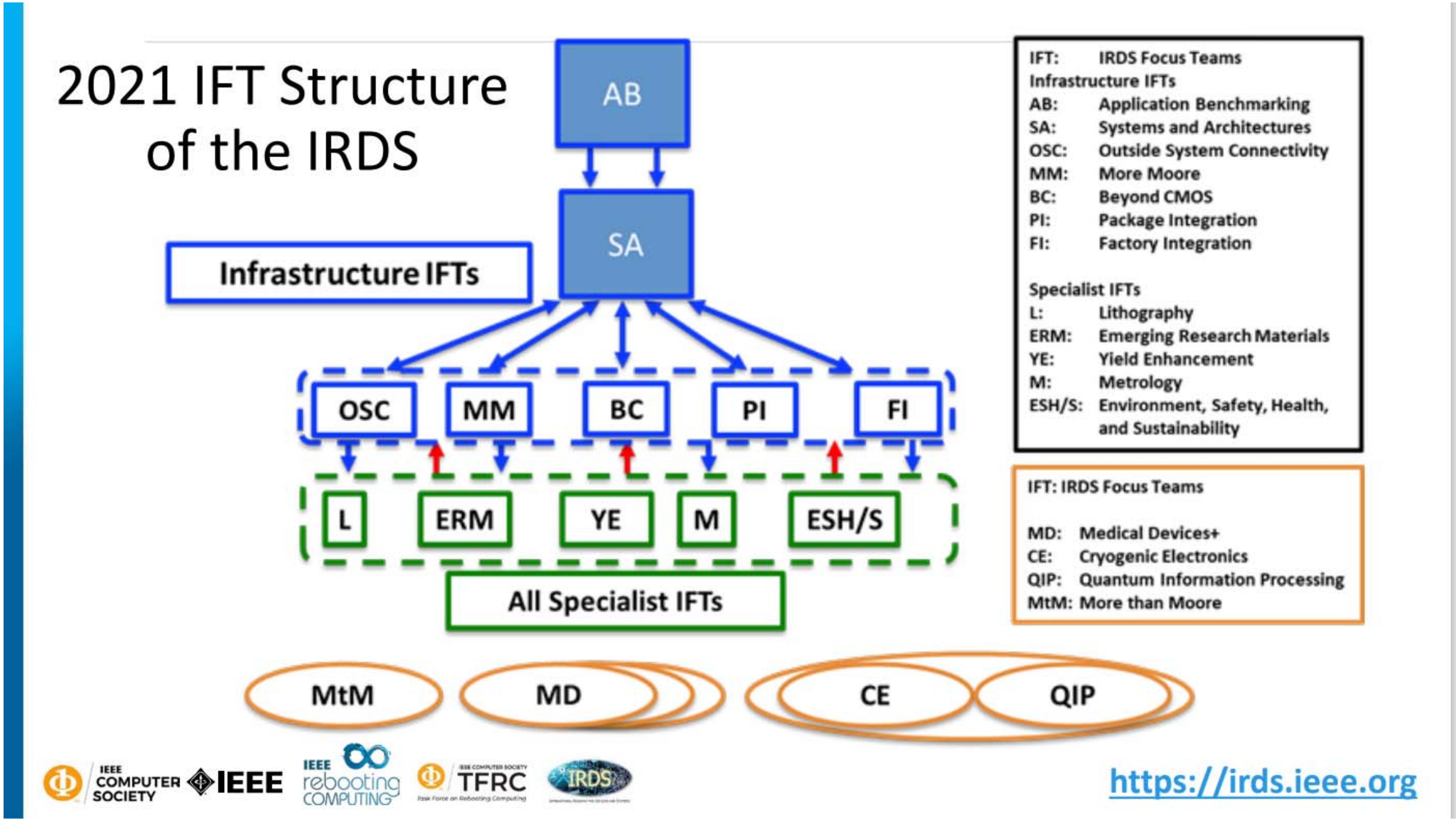

2021 IFT Structure of the IRDS

IFT: IRDS Focus Teams
Infrastructure IFTs
AB: Application Benchmarking
SA: Systems and Architectures
OSC: Outside System Connectivity
MM: More Moore
BC: Beyond CMOS
PI: Package Integration
FI: Factory Integration

Specialist IFTs
L: Lithography
ERM: Emerging Research Materials
YE: Yield Enhancement
M: Metrology
ESH/S: Environment, Safety, Health, and Sustainability

IFT: IRDS Focus Teams

MD: Medical Devices+
CE: Cryogenic Electronics
QIP: Quantum Information Processing
MtM: More than Moore

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Roadmap Key Outcomes

- Focuses research and development efforts
- Highlights the emerging technologies for devices and systems
- Suggests potential solutions for industry to resolve technology gaps and challenges

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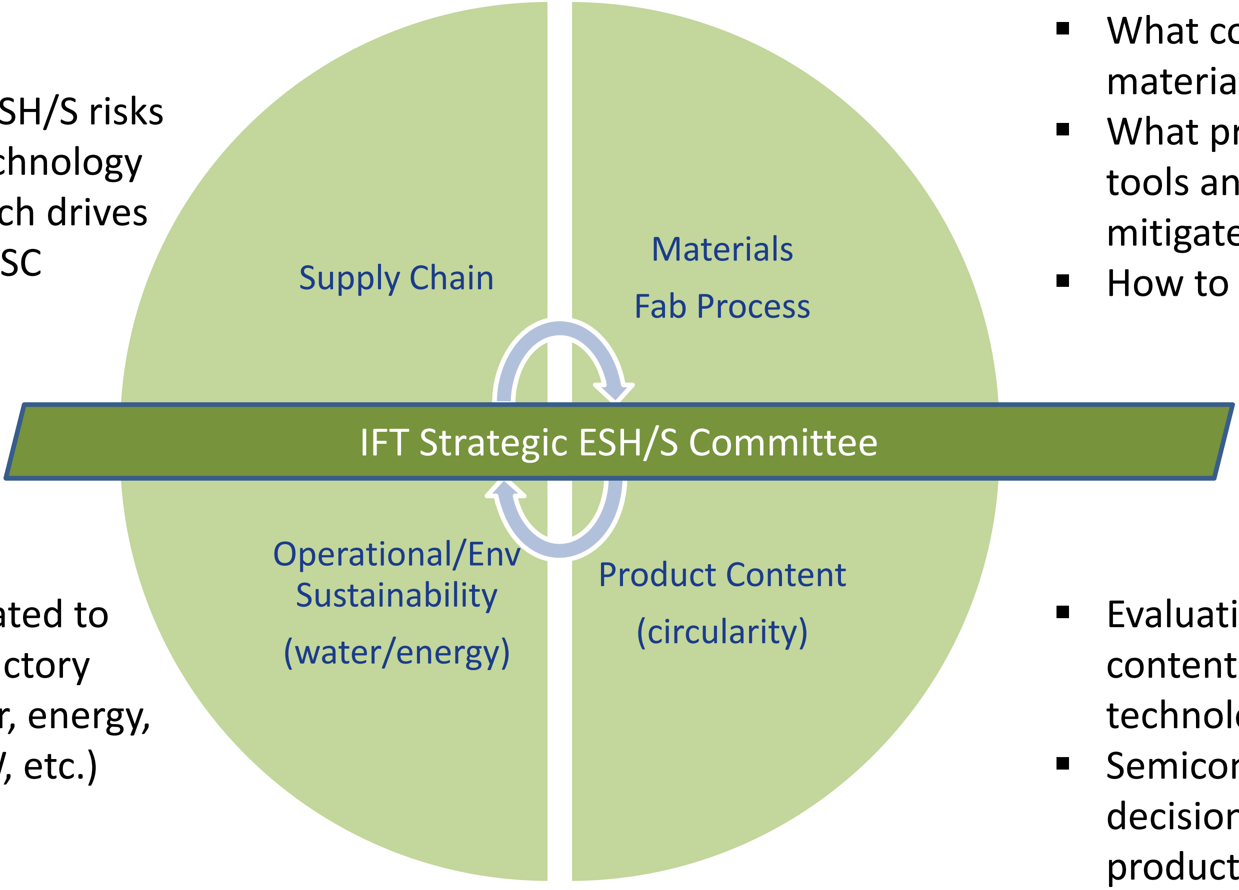
External landscape-challenges and issues

- Increasingly complex environment
  - Products/technologies/materials/regulations/trade/supply chain
  - Market demand changes vs. commits for capacity growth in EU and US
- Resource constraints, R&D pipeline challenges, workforce development
- Segmented operational approach to ESH, managed reactively, viewed as a tax
- Global sustainability challenges (water, energy, materials availability)
- Diminished focus on pre-competitive systems, esp. ESH/S technology development, roadmaps, technical tools and processes (to design out emerging issues up front)
- Inadequate focus on devices and systems (sensors, photonics, packaging, electronics EOL), ESH/S gaps downstream in the technology life cycle
- Lack of coordination and alignment between ESH/S initiatives (resource constraints, prioritization and integration gaps)

ESH/S IFT Team Structure, key focus areas

- Mapping key SC challenges into ESH/S risks
- An integrated technology roadmap approach drives prioritization for SC

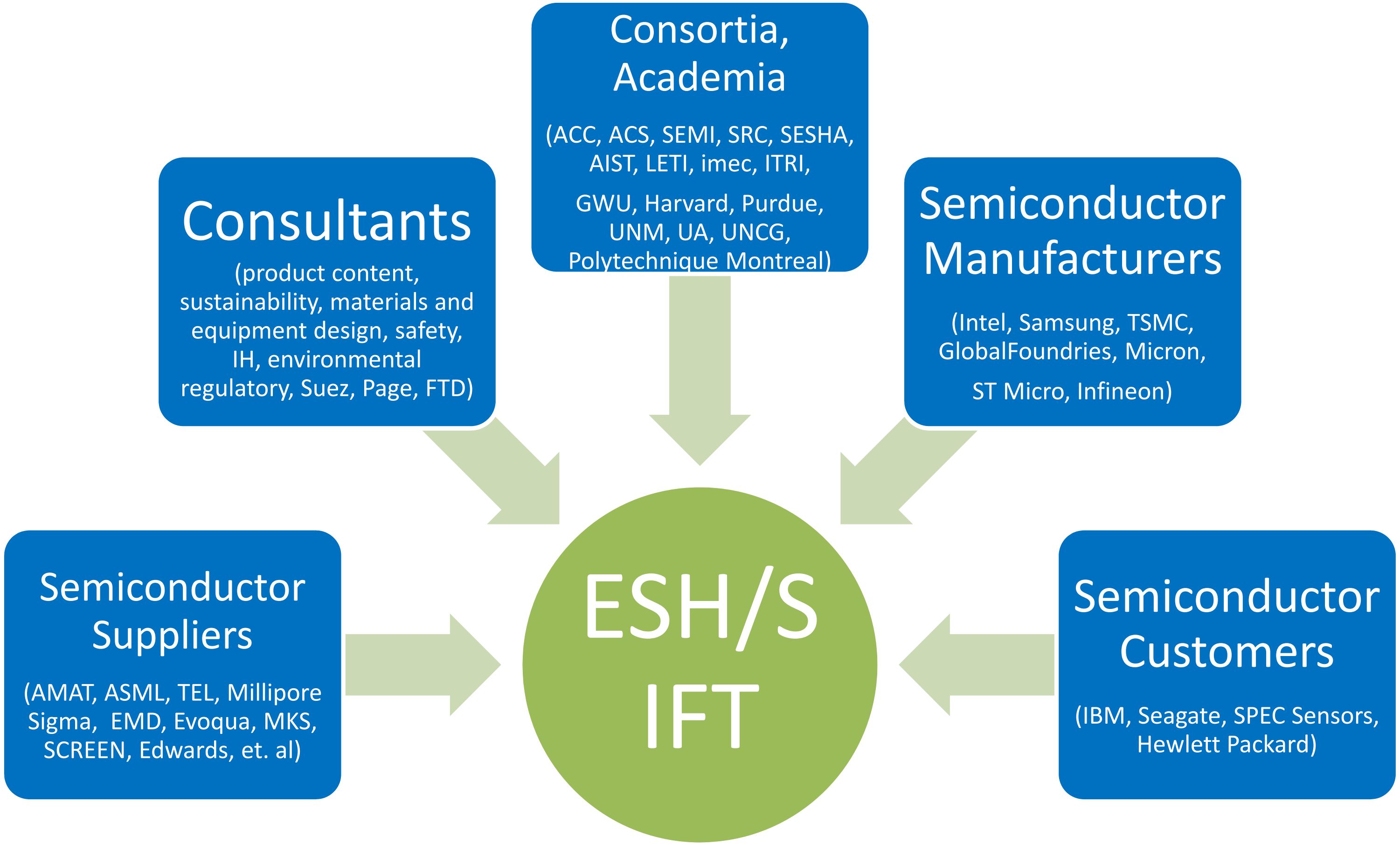
- What constitutes critical materials?
- What proactive, technical tools and systems can mitigate long term risk?
- How to avoid the next PFAS?



- Sustainability related to semiconductor factory operations (water, energy, wastewater, UPW, etc.)

- Evaluating product content issues across the technology life cycle
- Semiconductor process decisions informed by product content requirements (circularity)

Team Org Representation



Consortia, Academia

(ACC, ACS, SEMI, SRC, SESHA, AIST, LETI, imec, ITRI,

GWU, Harvard, Purdue, UNM, UA, UNCG, Polytechnique Montreal)

Consultants

(product content, sustainability, materials and equipment design, safety, IH, environmental regulatory, Suez, Page, FTD)

Semiconductor Manufacturers

(Intel, Samsung, TSMC, GlobalFoundries, Micron,

ST Micro, Infineon)

Semiconductor Suppliers

(AMAT, ASML, TEL, Millipore Sigma, EMD, Evoqua, MKS, SCREEN, Edwards, et. al)

ESH/S IFT

Semiconductor Customers

(IBM, Seagate, SPEC Sensors, Hewlett Packard)

Difficult Challenges

Challenges (near and long term)	*Summary of Issues (why is it a challenge?)*
Chip Demand	Infrastructure and resource constraints, rapid growth drives short term, tactical approach to ESH/S
Inability to effectively resolve known issues	PFAS and related materials identified previously, now dominating ESH/S industry resources (myopic impact?)
Climate change both with regard to compliance, external operational impacts	Higher cooling and air conditioning requirements, more abatement technologies with higher utility consumptions, meet needs for giga fabs
Changes in semiconductor technologies, e.g. EUV, 3D structures etc.	More process steps with higher energy and resource consumptions, new materials with new disposal challenges
Corporate sustainability (commits vs. technical drivers)	Net carbon neutrality, regulatory requirement, disclosure
Product content challenges (how to address fundamentally unrecyclable materials (i.e., epoxy, silicon die, etc.)	Defining sustainability-related requirements for materials that are fundamental and critical to semiconductor technology but have never been assessed for sustainability will require significant data and justification.
Workforce development	Education, training, research capability gap in resourcing (esp. for ESH/S TD) (insufficient engineering and science grads to meet industry needs)
Inadequate proactive, pre-competitive technical systems for driving ESH/S technology development initiatives	Without senior, exec level championing of ESH/S technology Roadmapping and development, there are no business objectives in place (and no dedicated resources for taking a long-term approach to effectively deal with the design out emerging challenges

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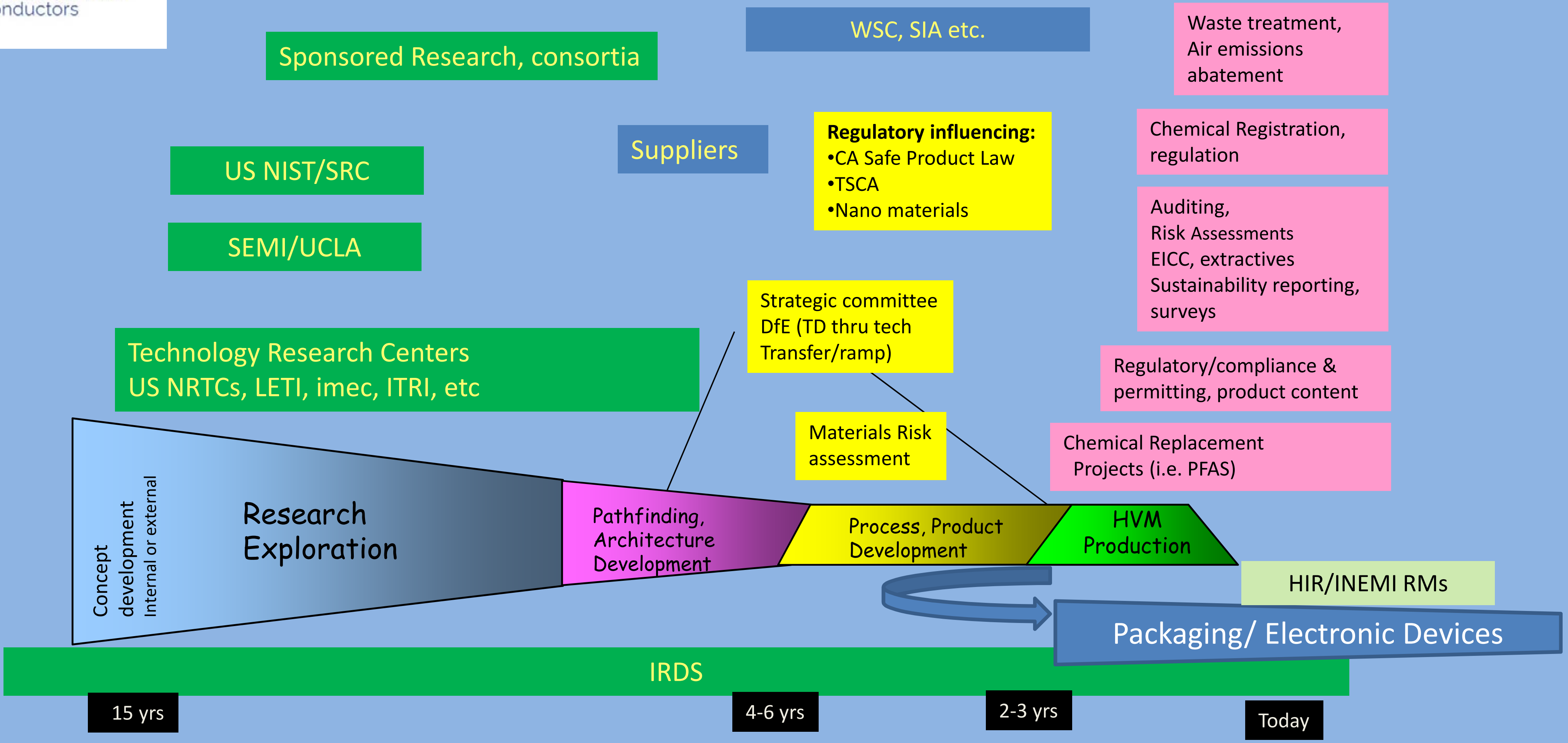
Technical decision making, ESH/S engagements and the Technology Life cycle



Sponsored Research, consortia

WSC, SIA etc.

Waste treatment,
Air emissions
abatement

US NIST/SRC

SEMI/UCLA

Suppliers

Regulatory influencing:
- CA Safe Product Law
- TSCA
- Nano materials

Chemical Registration,
regulation

Auditing,
Risk Assessments
EICC, extractives
Sustainability reporting,
surveys

Strategic committee
DfE (TD thru tech
Transfer/ramp)

Technology Research Centers
US NRTCs, LETI, imec, ITRI, etc

Regulatory/compliance &
permitting, product content

Materials Risk
assessment

Chemical Replacement
Projects (i.e. PFAS)

Concept
development
Internal or external

Research
Exploration

Pathfinding,
Architecture
Development

Process, Product
Development

HVM
Production

HIR/INEMI RMs

Packaging/ Electronic Devices

IRDS

15 yrs

4-6 yrs

2-3 yrs

Today

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→Designing out emerging EHS/S challenges is about effective decision making, long-range risk assessments and timing of ESH/S engagement

2022 Roadmap (RM) Summary – ESH/S IFT

- Restart of ESH/S section in mid-Q1’22 after 6+ years of inactivity, based on core principles of prior successful RM iterations (half day workshop focus on key risk areas), establishing:
  - Strategic Oversight Committee (to manage external driver engagement, scope between teams)
  - Sub-team (ST) Work Groups: Environmental Sustainability of Semiconductor Facilities (water/energy), Product Content, Supply Chain, Materials/fab process
  - Participation amongst teams for the ESH/S IFT through 2022, by >100 reps from Asia, NA and Europe
- The output of this road-mapping efforts by the working group sub teams is a Roadmap Chapter (White Paper), in early Q2 of 2023
- Primary WP content focused on Environmental Sustainability (water/energy) ST, demonstrating:
  - The fundamental effectiveness of the technology roadmap process, as it was at the time of ITRS
  - Strong representation by semiconductor suppliers and manufacturer content experts
  - Development of comprehensive water/energy models and KPIs to enable more effective decision making
- The other three STs developed charter documents, initial scope and key issues of focus for 2023
- Strengthened connections within the IRDS IFTs, with key stakeholders and external entities

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Example: Litho-ESH/S challenges

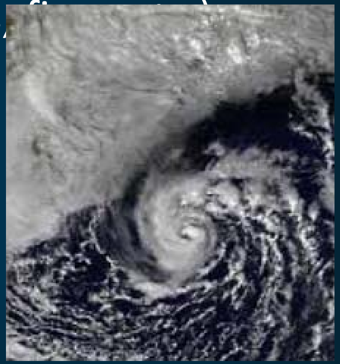
- Increasing demand for semiconductor devices is driving consumption of more resources for semiconductor manufacturing
  - Particularly for key lithography processes
    - Electricity*
    - Chemicals
    - Water
- There are on-going activities to address
  - Reduction of electricity consumption
  - Means of abatement of fluorine-containing chemicals (in wastewater discharge)
  - Alternatives to fluorine-containing chemicals (materials development)
  - Additional materials of concern for ESH/S impact (VOC emissions, TMAH in developers, etc.)
  - Role of litho in packaging
  - Development of dry processes

Environmental Sustainability of Semiconductor Facilities (ESSF) ESH/S IRDS

04/24/2023

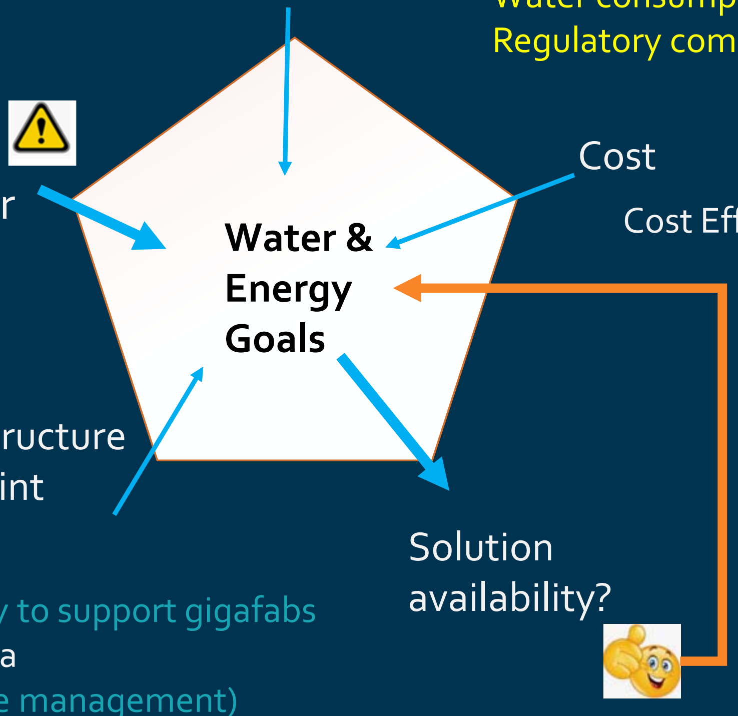
The Perfect Storm

- Growing industry challenges in the space of environmental sustainability requires clear understanding of the industry drivers and needs to support technology development to address those challenges
- The industry is pursuing unprecedented growth: building new very large fabs, expanding existing ones, or increasing output of currently operating ones, while
  - Next generation fabs drives exponentially growing environmental footprint
  - Environmental conditions are deteriorating (drought, flooding, hurricanes,
  - Environmental regulations get stricter
  - Companies’ ESG commitments get tighter
- New challenges require new technological solutions



IRDS W+E Roadmap Ecosystem

Legend:
Energy driver
Water driver
Energy & water driver



Process driver
EUV
Increasing # of steps
Increasing # of CMP steps
Single wafer clean

Semiconductor Technology

ESG Compliance

Carbon footprint reduction
Chemical consumption reduction
Water consumption reduction
Regulatory compliance (e.g. PFAS)

Cost

Cost Efficiency
- Gigafabs enabling (size and complexity)
- Yield and ITP Management

Water & Energy Goals

Infrastructure footprint

Location Specific

Water & Energy availability to support gigafabs
Raw water quality, e.g. urea
Discharge limits (e.g., brine management)
Other regulations, recycling, use of waste water

Solution availability?

Solutions Enabled by IRDS Roadmap

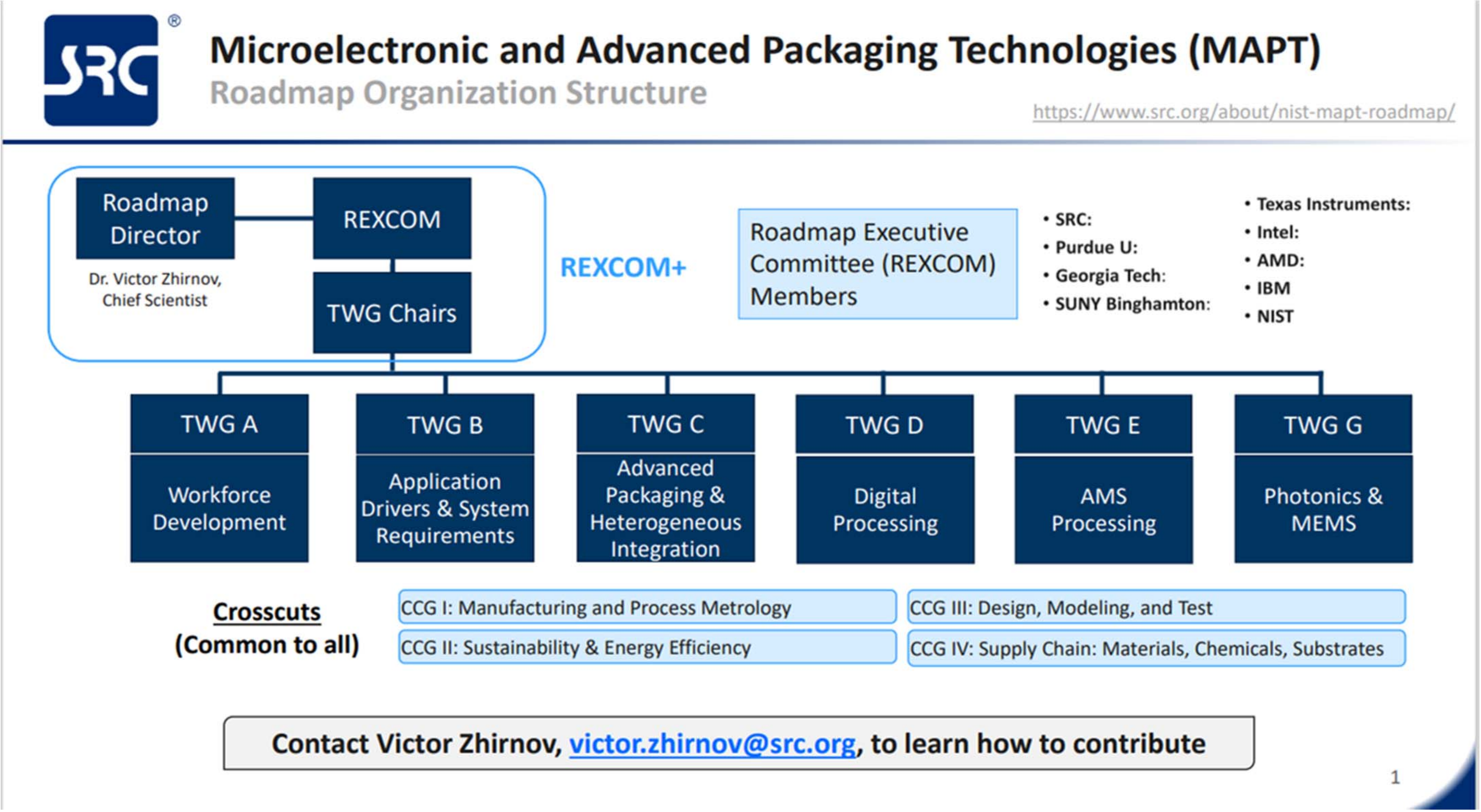
Goals and Scope of W+E Roadmap

- Provide industry supply chain with justification for the new solutions development that will enable sustainable industry growth
- Develop tangible roadmap targets for solution requirements in the areas of high risk, including
  - Justification for the solution requirements
  - Key performance indicators (KPIs)
- Scope includes all systems within semiconductor manufacturing facility with meaningful, emissions, water, energy, and waste footprint.
  - Energy includes electricity and fuel gas, as well as any significant consumables production of which requires significant amounts of energy (i.e., pure gases, CDA, chemicals, etc.)

Process/Progress

- 2022 (complete – the sub-chapter is pending review)
  - Identify roadmap implications – qualify drivers
  - Confirm roadmap relevant boundaries, e.g. ESG & infrastructure, site specific versus common/global
  - Develop representative site water and energy models
  - Conduct Technology Gap Analysis
    - Quantify technology needs – Parameters/KPIs for water and energy consumption
    - Identify critical challenges
  - Publish the roadmap
- 2023 – deeper dive into priority issues
  - Universal Env Sustainability KPI
  - Refine Water and Energy Models
  - Define Scope 3 relevant to ESSF
  - Tools and Key Components
  - Regulations and Commitments

Initiatives and Strategies



Microelectronic and Advanced Packaging Technologies (MAPT)

Roadmap Organization Structure

https://www.src.org/about/nist-mapt-roadmap/

Roadmap Director

Dr. Victor Zhirnov, Chief Scientist

REXCOM

TWG Chairs

REXCOM+

Roadmap Executive Committee (REXCOM) Members

- **SRC:**
- **Purdue U:**
- **Georgia Tech:**
- **SUNY Binghamton:**

- **Texas Instruments:**
- **Intel:**
- **AMD:**
- **IBM**
- **NIST**

TWG A	TWG B	TWG C	TWG D	TWG E	TWG G
Workforce Development	Application Drivers & System Requirements	Advanced Packaging & Heterogeneous Integration	Digital Processing	AMS Processing	Photonics & MEMS

Crosscuts (Common to all)

- CCG I: Manufacturing and Process Metrology
- CCG II: Sustainability & Energy Efficiency
- CCG III: Design, Modeling, and Test
- CCG IV: Supply Chain: Materials, Chemicals, Substrates

Contact Victor Zhirnov, victor.zhirnov@src.org, to learn how to contribute

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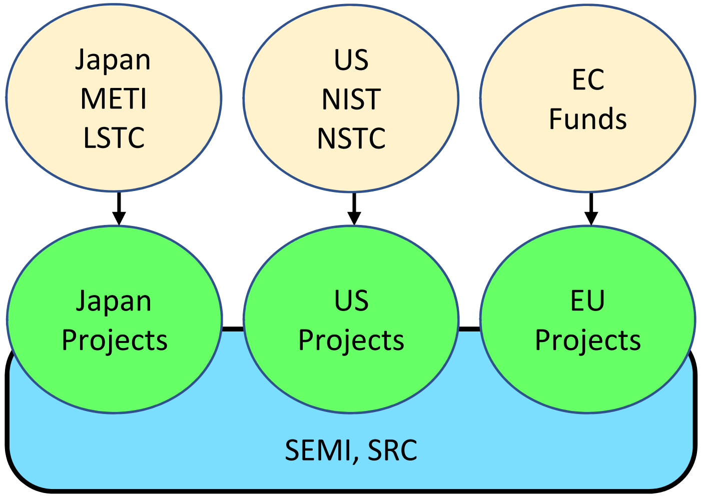
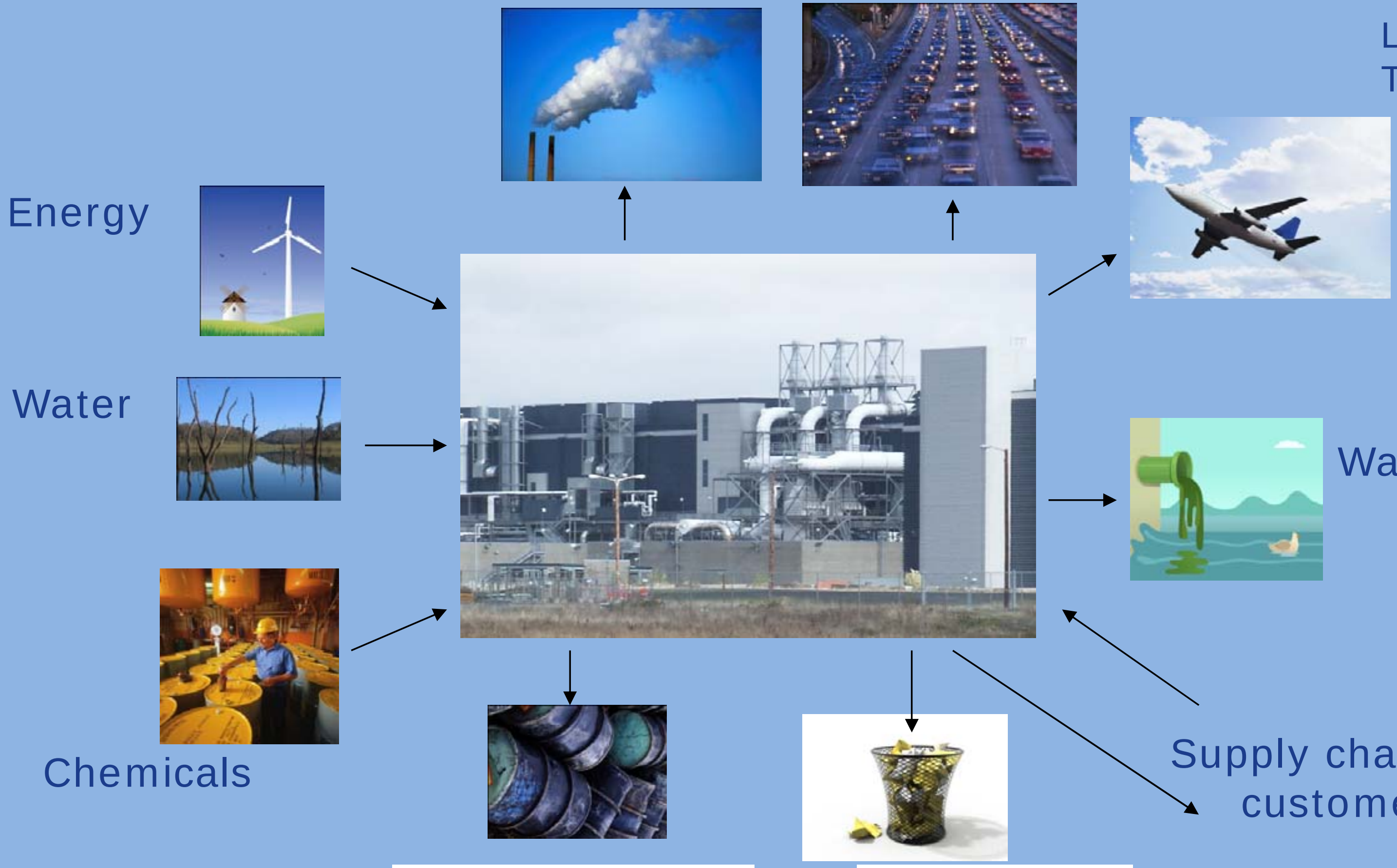
Sustainable Semiconductor Manufacturing (SSM)

Proposed Initiative

- Regional governments provide funds for companies and universities to explore sustainable semiconductor manufacturing R&D projects in their region
    - METI and LSTC in Japan
    - NIST and NSTC in the US
    - European Commission (Horizon Europe)
- Projects could be contracted through SEMI and the Semiconductor Research Corporation (SRC), which provide a central coordination and data sharing role
- This alliance helps with eliminating redundancies and leveraging learnings between regions
- An industry-wide strategy is urgently needed to deal with 3-M’s shut down of PFAS production in 2025 and growing environmental regulations



Integrated management of TD EHS/S at a factory level



Air Pollution (VOC, HAP)

Global Warming Gases

Logistics &
Transport

Energy

Water

Wastewater

Chemicals

Supply chain and
customers

Chemical Waste

Solid Waste

Conclusions

Summary:

- We are at an environmental/sustainability precipice, requiring a fundamentally different approach (a short term, reacting to regulations and external drivers is not viable)
- Prior effectiveness of the technology RM for ESH/S is well documented, and key to addressing ESH/S issues (serves to define vision and direction for an integrated path forward)
- Substantive roadmap chapter results from the Environmental Sustainability section for Semiconductor Facilities demonstrates the unique value and importance for employing the Technology Roadmap for ESH/S
- The ESH/S IFT reset and results to date have been significant, BUT:
  - Continued IFT member engagement and resourcing is lacking
  - Executive level championing of the ESHS technology roadmap efforts is a MUST
- Driving circularity across the technology life cycle (semiconductor-packaging- electronics) provides feedback regarding product content issues upstream, and enables shared learnings from semiconductor manufacturing

Call to Action:

- ➢ Senior level leaders dedicate resources (both technologists and ESH/S content experts) for precompetitive initiatives (roadmaps, technology development) as well as funding
- ➢ Drive alignment and coordination of ESH/S initiatives to ensure an integrated approach between R&D, manufacturing, government, academic and commercial (supply chain) perspectives
- ➢ 'the ultimate end in mind' = taking industry Roadmap driven solutions and apply these to broader external challenges globally *(work for the environment, not just be compliant and less bad)*

THANK YOU

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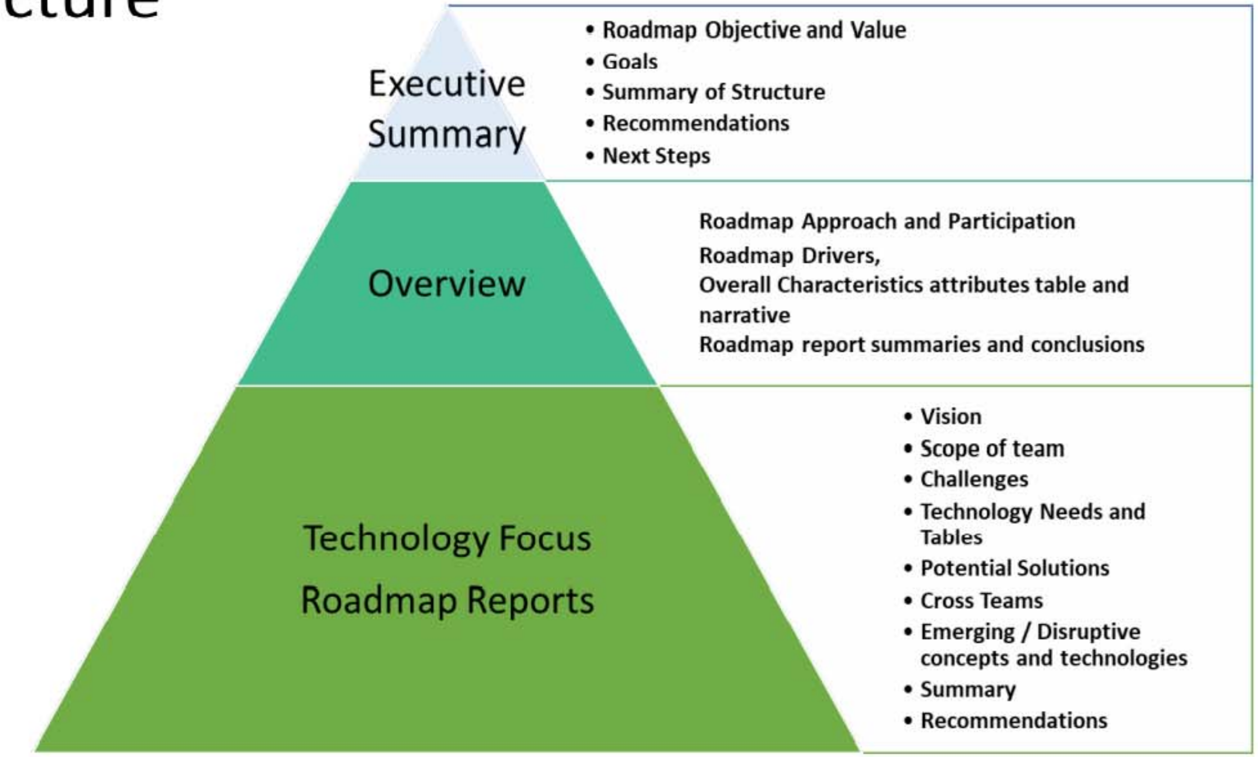
WORKSHOP - Sustainable Electronics & International Cooperation On Semiconductors

www.icos-semiconductors.eu

Back-up

Content Structure



Executive Summary

- Roadmap Objective and Value
- Goals
- Summary of Structure
- Recommendations
- Next Steps

Overview

Roadmap Approach and Participation

Roadmap Drivers,

Overall Characteristics attributes table and narrative

Roadmap report summaries and conclusions

Technology Focus Roadmap Reports

- Vision
- Scope of team
- Challenges
- Technology Needs and Tables
- Potential Solutions
- Cross Teams
- Emerging / Disruptive concepts and technologies
- Summary
- Recommendations

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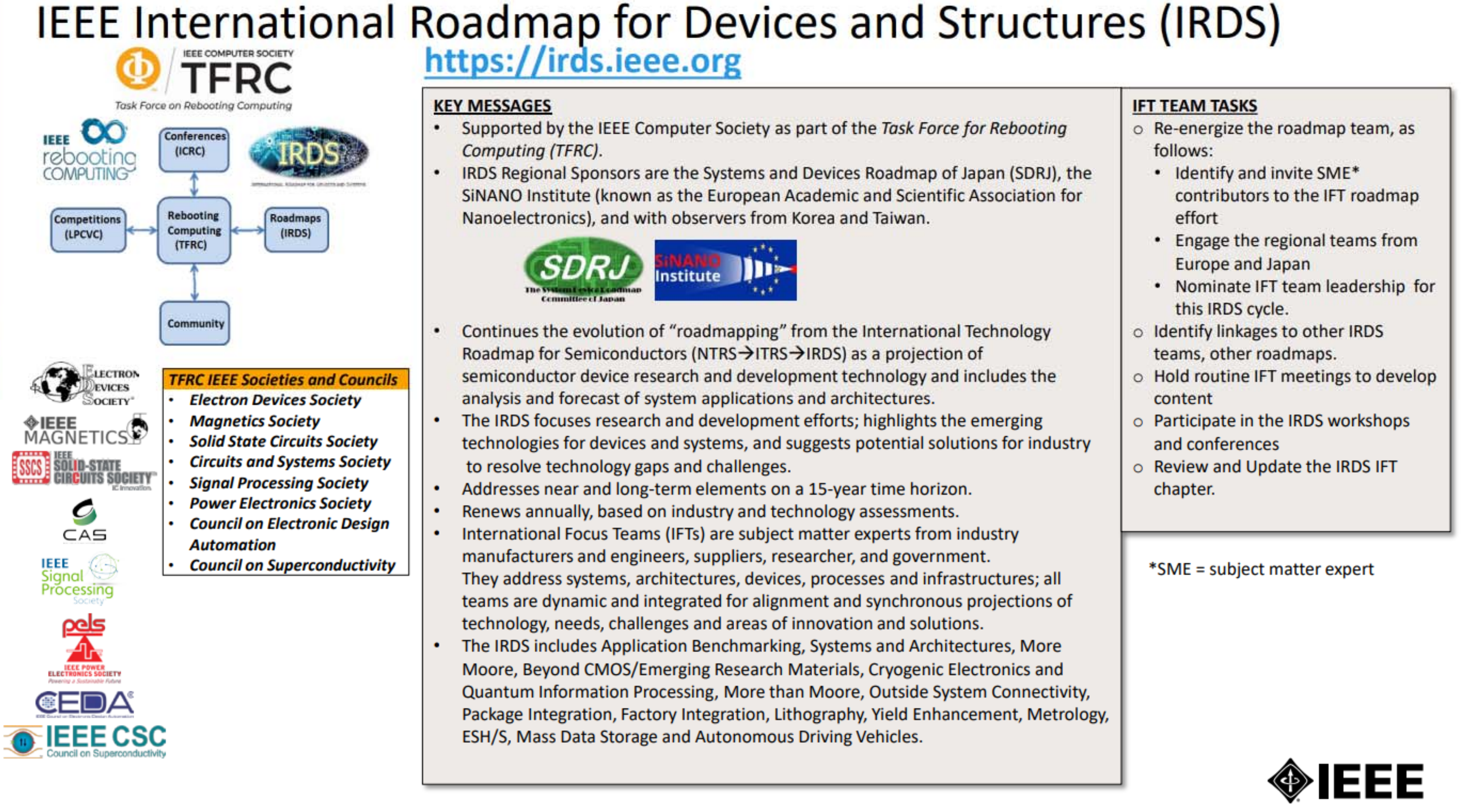


IEEE International Roadmap for Devices and Structures (IRDS)

https://irds.ieee.org

TFRC IEEE Societies and Councils

- ***Electron Devices Society***
- ***Magnetics Society***
- ***Solid State Circuits Society***
- ***Circuits and Systems Society***
- ***Signal Processing Society***
- ***Power Electronics Society***
- ***Council on Electronic Design Automation***
- ***Council on Superconductivity***

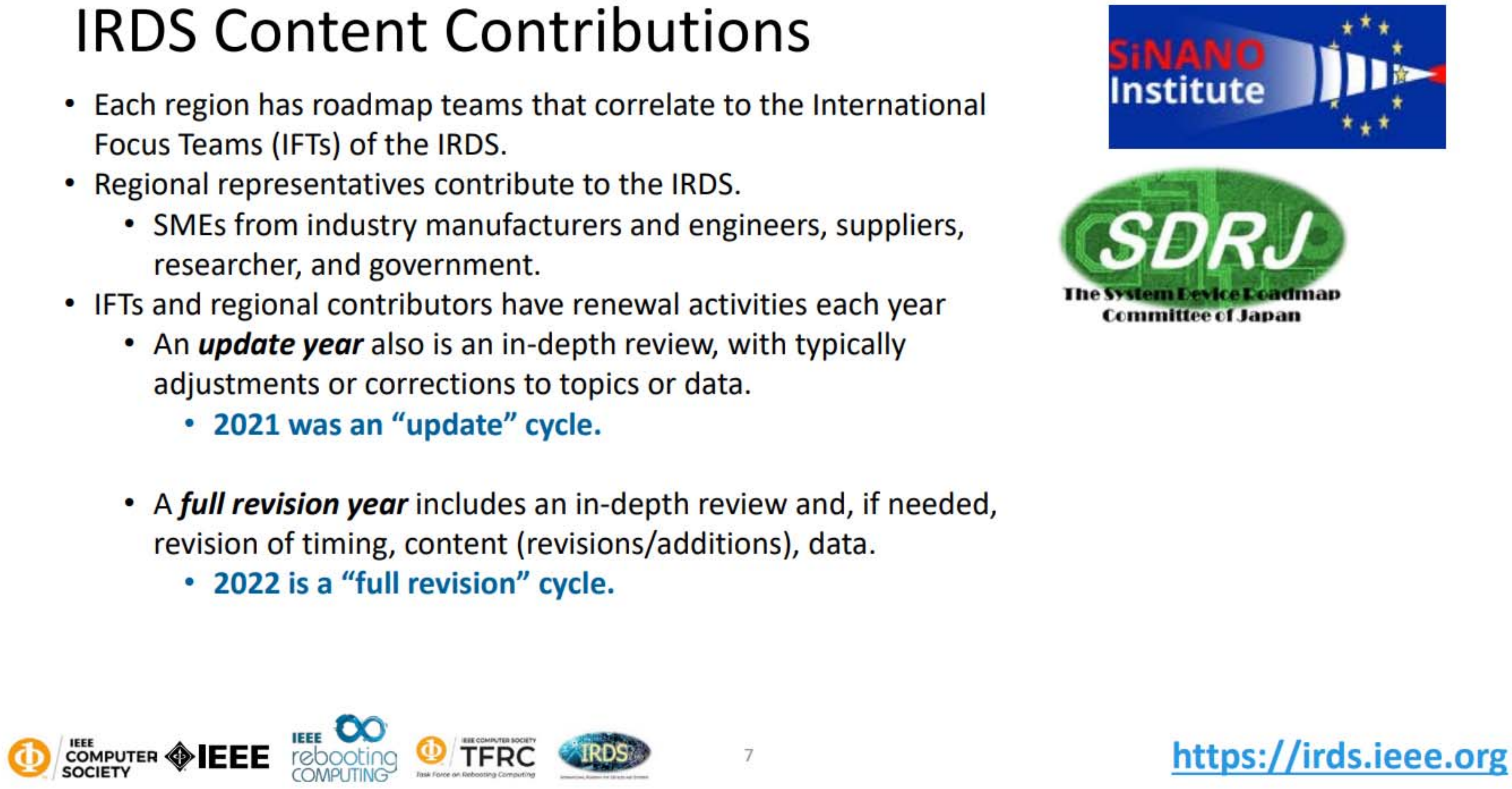
KEY MESSAGES

- Supported by the IEEE Computer Society as part of the *Task Force for Rebooting Computing (TFRC).*
- IRDS Regional Sponsors are the Systems and Devices Roadmap of Japan (SDRJ), the SiNANO Institute (known as the European Academic and Scientific Association for Nanoelectronics), and with observers from Korea and Taiwan.
- Continues the evolution of "roadmapping" from the International Technology Roadmap for Semiconductors (NTRS→ITRS→IRDS) as a projection of semiconductor device research and development technology and includes the analysis and forecast of system applications and architectures.
- The IRDS focuses research and development efforts; highlights the emerging technologies for devices and systems, and suggests potential solutions for industry to resolve technology gaps and challenges.
- Addresses near and long-term elements on a 15-year time horizon.
- Renews annually, based on industry and technology assessments.
- International Focus Teams (IFTs) are subject matter experts from industry manufacturers and engineers, suppliers, researcher, and government. They address systems, architectures, devices, processes and infrastructures; all teams are dynamic and integrated for alignment and synchronous projections of technology, needs, challenges and areas of innovation and solutions.
- The IRDS includes Application Benchmarking, Systems and Architectures, More Moore, Beyond CMOS/Emerging Research Materials, Cryogenic Electronics and Quantum Information Processing, More than Moore, Outside System Connectivity, Package Integration, Factory Integration, Lithography, Yield Enhancement, Metrology, ESH/S, Mass Data Storage and Autonomous Driving Vehicles.

IFT TEAM TASKS

- Re-energize the roadmap team, as follows:
  - Identify and invite SME* contributors to the IFT roadmap effort
  - Engage the regional teams from Europe and Japan
  - Nominate IFT team leadership for this IRDS cycle.
- Identify linkages to other IRDS teams, other roadmaps.
- Hold routine IFT meetings to develop content
- Participate in the IRDS workshops and conferences
- Review and Update the IRDS IFT chapter.

*SME = subject matter expert



IRDS Content Contributions

- Each region has roadmap teams that correlate to the International Focus Teams (IFTs) of the IRDS.
- Regional representatives contribute to the IRDS.
  - SMEs from industry manufacturers and engineers, suppliers, researcher, and government.
- IFTs and regional contributors have renewal activities each year
  - An ***update year*** also is an in-depth review, with typically adjustments or corrections to topics or data.
    - **2021 was an "update" cycle.**
  - A ***full revision year*** includes an in-depth review and, if needed, revision of timing, content (revisions/additions), data.
    - **2022 is a "full revision" cycle.**

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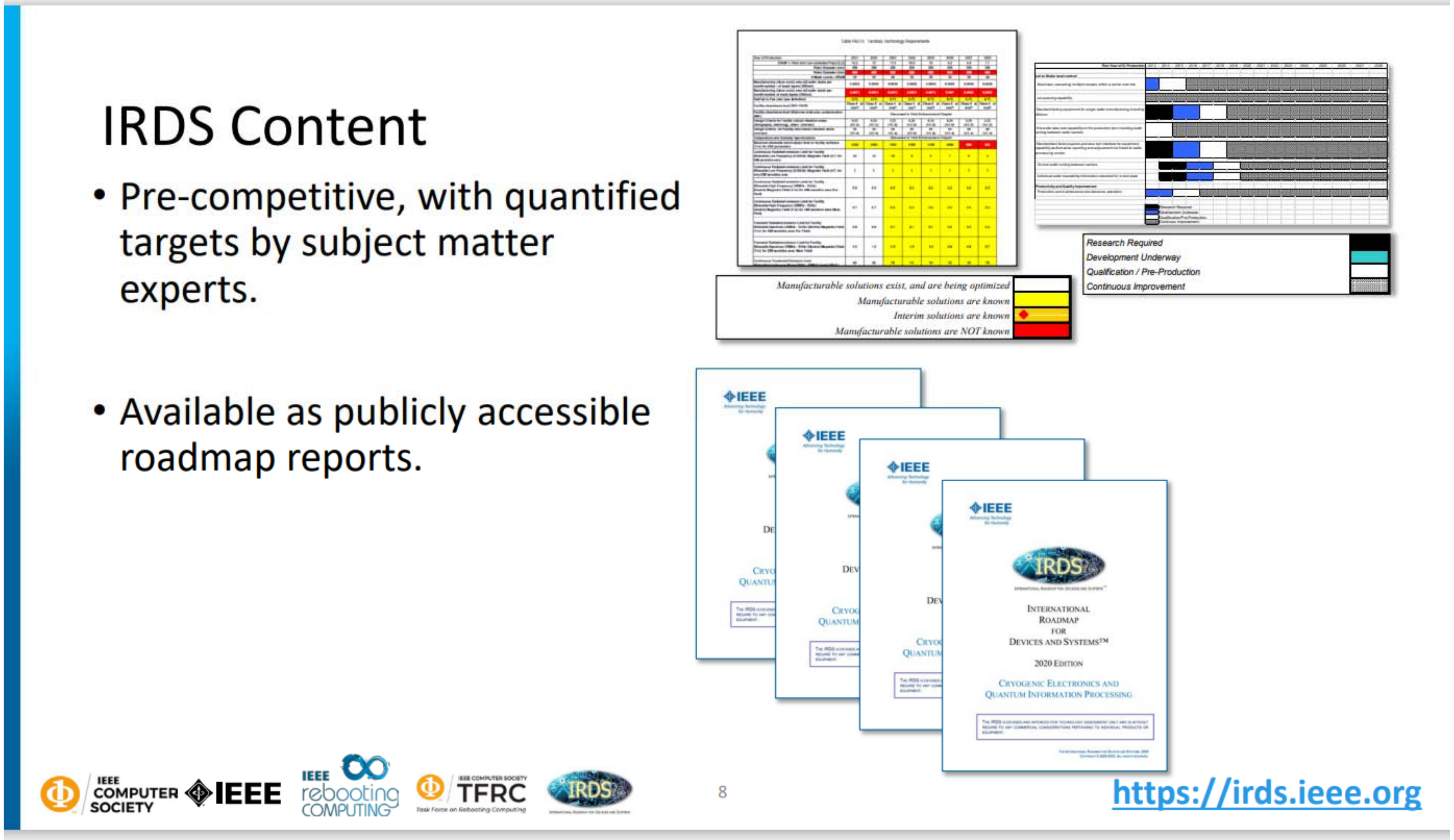

IRDS Content

- Pre-competitive, with quantified targets by subject matter experts.
- Available as publicly accessible roadmap reports.

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	🟨 ◆
Manufacturable solutions are NOT known	🟥

Research Required	⬛
Development Underway	🟦
Qualification / Pre-Production	⬜
Continuous Improvement	▨

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IRDS
INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™
2020 EDITION
CRYOGENIC ELECTRONICS AND QUANTUM INFORMATION PROCESSING

IEEE COMPUTER SOCIETY IEEE IEEE rebooting COMPUTING IEEE COMPUTER SOCIETY TFRC Task Force on Rebooting Computing IRDS

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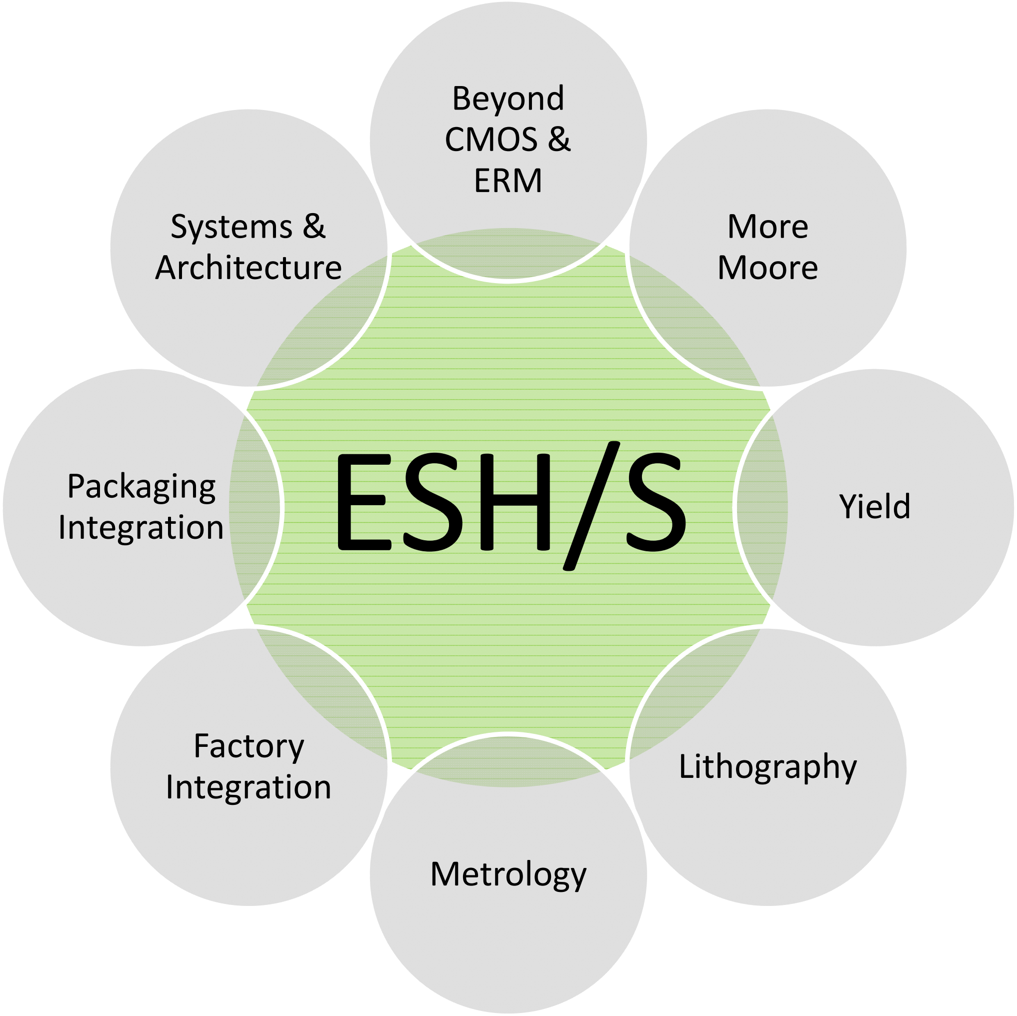
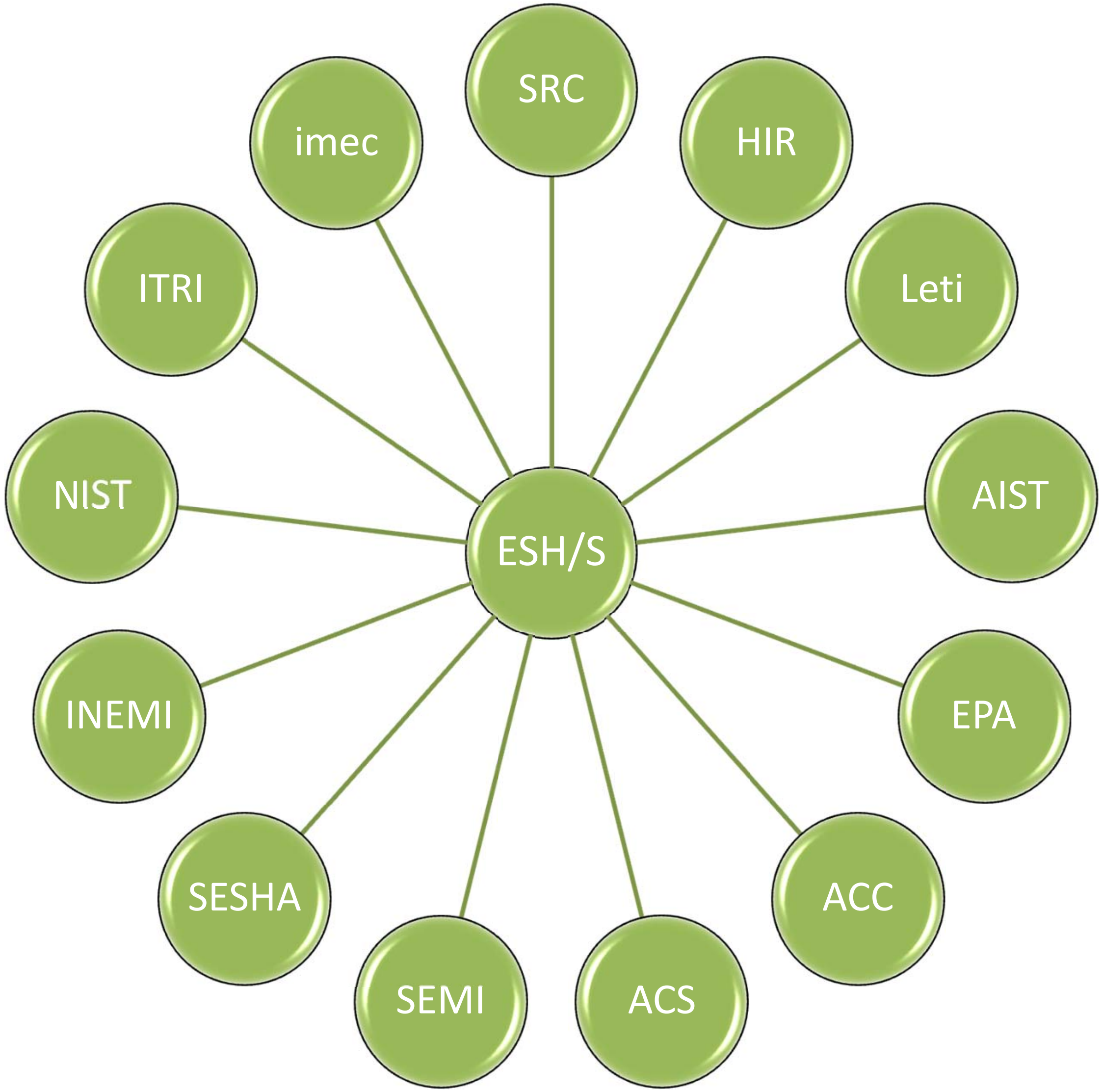
IRDS ESH/S IFT Cross-team Alignments

→Regular collaboration and coordination between the Functional teams is part of the technology roadmap process, to ensure that emerging developments in the respective disciplines are evaluated in terms of their potential ESH/S impacts, which are then integrated into the roadmap as challenges and risks that need to be addressed



External Roadmap Collaborations



ESH/S

SRC

HIR

Leti

AIST

EPA

ACC

ACS

SEMI

SESHA

INEMI

NIST

ITRI

imec

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Jim Snow	Screen
Josh Best	FTD

Kevin Geoghegan	Intel, co-chair
Laura Demmons	Sylvan Source
Leo Kenny	Planet Singular
Mike Knapp	Samsung
Marina Cameron	FTD
Paul Kerr	Intel, co-chair
Paul Peyrot	Leti
Peter Navaneethakrishnan	Micron
Phil Naughton	Applied Materials
Rama Krishna Rao Gowd Ede	AMAT
Rich Riley	Intel
Sena Shim	Samsung
Simon Lin	TSMC
Slava Libman	FTD Solutions, co-chair
Taewoan Koo	Samsung
Varinder Malik	Samsung
Sébastien Godat	Leti
Marcel Teunissen	ASML
Chris Jones	Edwards
Bram Vangestel	IMEC
Takumi Mikawa	Screen
Joel Barnett	TEL

Boundaries and Drivers

Drivers (mission critical)
Semiconductor Technologies
New Materials
Process/Tool Changes (i.e., EUV)
Many more process steps (high UPW usage)
Growing facility complexity and size
ESG – Corporate Sustainability
Freshwater consumption reduction/ Water reuse
CO2 emission
Wastewater pollution (TDS, toxic compounds)
Chip Demand
Climate Change

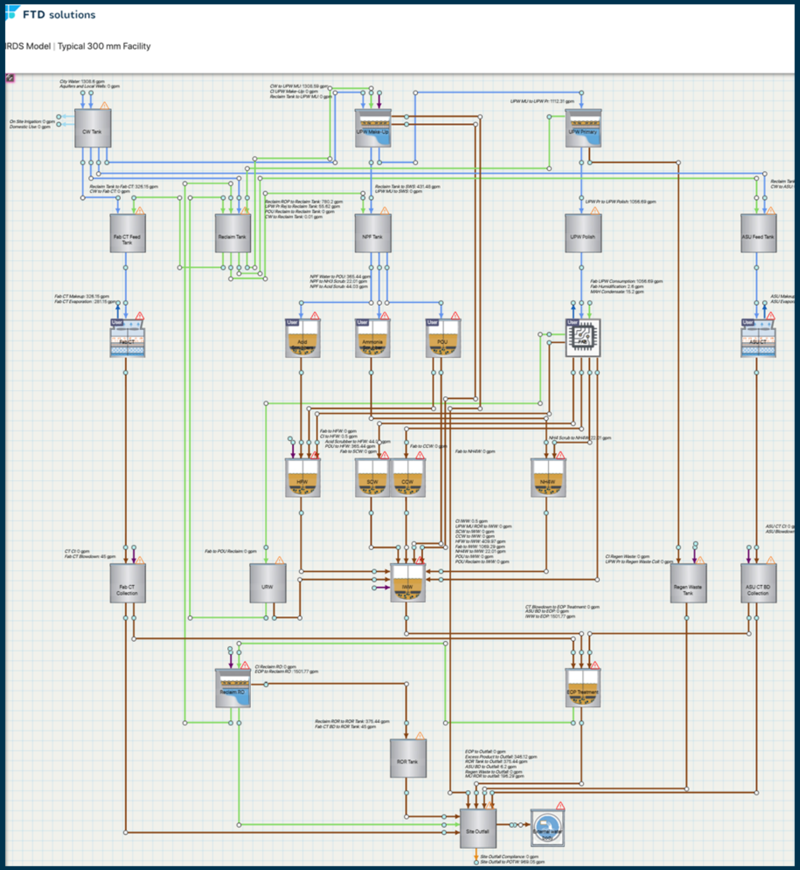
Boundaries
External Water Infrastructure
Environmental Compliance
Facility Reliability (0 ITP)
Space
Safety

Considerations
Cost
Solution Availability
Freshwater Resources
Freshwater quality
Discharge Options
Waste Disposal Options
Energy infrastructure availability
External Reclaim Options
Staffing Availability
Supply Chain Capability
UPW quality requirements
Reliability/Redundancy/Outage Behavioral (unscheduled dump, inaccurate sizing, excessive rinses, maintenance inefficiency)

Growing risk

Gap Analysis Using Site Water Modeling

- Flow/chemistry balance
- Technology Roadmap Representative site
- Water demand per type of users (process and non-process)
- Major chemistry input to assess implications to compliance
- Reclaim (KPI, definitions, industry targets driven by existing corporate commitments)



Critical Challenges

- Reduction of CT evaporation
    - Problem – water consumption (loss to the watershed); lack of coordinated approach leads to lost conservation opportunities
    - Information needed – quantities; energy conservation and heat recovery opportunities; complete the Water and Energy Models
    - Technology solutions - heat recovery approaches, recovering water from vapor or drift reduction
    - Potential solution – maximize implementation of the heat recovery solutions, consider options for allowing for high temperature environment – allowing for heat dissipation (align with Energy team)
- PFAS control
    - Problem – timing of regulatory changes, lack of clarity on pending limits, lack metrology to support currently discussed targets, mission critical applications requiring use of PFAS (may be leaching into effluent streams)
    - Opportunity - coordinated approach across the industry
    - Information needed – emission quantities, emissions requirements/targets, are PFAs limits liquid only or will we have gas emission limits?
    - Technology solutions required – reliable analytical methods, treatment solutions (driven by future requirements)
    - Potential solutions – ZLD; Merck/Micron – check the status of the development LGWP solutions –etching gas – PFAS free (multi-stage approach)
- Brine management with low/no CO2 emission (low or renewable energy)
    - Problem – energy intensive process, highly specialized equipment, regulatory discharge environment (sulfates, TDS, etc.), highly site-specific requirements, conventional thermal system is very sensitive to incoming chemistry changes
    - Information needed – emissions limits, effect of PFAs regulations (can be a driver for ZLD), quantities of chemistry (water model), new materials hitting the process, external infrastructure needs
    - Technology solutions – higher recovery fouling/scaling resistant preconcentration (I.e., RO, EDR, etc.), potential alternates to thermal evaporation, metrology solutions to optimize system operation
    - Potential solutions: leverage existing preconcentration solution to their maximum ability; explore innovative options that exist (risk needs to be managed)
- Effective metrology for wastewater
    - Problem – regulatory limits on other compounds (e.g. azoles?), discharge limits getting lower, online vs grab (include reliability and sensitivity) - need specific parameters that require metrology
    - Information needed – new materials hitting the process, emission quantities, emissions limits or target values, potential analytical methods for compounds identified
    - Technology solutions – developing more online metrology, including POU metrology for both energy, exhaust, and water monitoring
        - Opportunity - coordinated approach across the industry
    - Potential solutions – until effective real time data exist, leverage existing metrology and engineering assessment to optimize operation

Critical challenges

- Chemistry Environmental Footprint
  - Chemistry/Water/Material Intensity involved with Water Management resulting in Environmental Footprint
  - Solution/Technology need – chemicals free wastewater treatment/reclamation, using more reclaim water for facilities treatment operations and cooling towers
- Technology for effective and timely decisions
  - Problem: proactive data management for capacity gap analysis and ongoing water management/planning to address global climate effects
    - Such as flooding/runoff, land sliding, droughts, MAH loads/evaporation, infrastructure availability, strong winds, snow loads, water quality deterioration, power outage (new design standards)
  - Solution: digital tools supporting data management and decision needs
  - Opportunity: Flag external infrastructure needs early with government agencies
- Fab tool water demand reduction
  - Problem: tool vendors provide options for optimization that are not always used
  - Solution: information, education, validation of those capabilities
  - POU recycling: may not be feasible due to space constraints
- Site water management optimization
  - Problem: High complexity of advanced semiconductor facility makes it difficult to make decisions on optimum site water management (planning)
  - Solution: holistic approach is needed to ensure environmental fooptrint reduction at lower cost, higher reliability etc.
  - Example: tool water demand reduction may affect Yield or reduce available reclaim for non-process application

Critical Challenges

- Problem: segregated concentrated chemical wastes need cost effective and environmentally friendly solutions for reuse or disposal
  - Sulfuric acid
  - Ammonium sulfate
  - CaF_2
  - Concentrated solvent waste (PMH, TMAH, IPA, polar and non-polar photoresist, etc.)

Back-up

Brainstorming Risks

Drivers (mission critical)	Risks of getting outside of the Boundaries
Semiconductor Technologies (node, generation)	
New Materials	*AR SL/LK obtain information on the materials that may **pose risks to environment*** - *May affect performance of existing treatment or requires new treatment technology* - *Some new chemistries cannot be discharged into effluent*
Process/Tool Changes (i.e., EUV)	*Increased evaporative cooling (EUV, metrology, etc.)*
Many more process steps (high UPW usage + high chemical consumption)	*Increasing water footprint, treatment chemicals (related to increased water consumption), fab chemistry usage*
Growing facility complexity and size	*Growing number and complexity of the water/wastewater treatment, segregation, and reclamation*
ESG – Corporate Sustainability	
Water reuse	*Higher reclaim results in the need of brine management (energy intensive/CO_2)*
CO_2 emission	*Driven by ZLD (driven by other factors)*
Wastewater pollution	*PFAS, etc.*
Chip Demand	Semiconductor facilities grow in sizes potentially exceeding capability of the external water infrastructure
Climate Change	Flooding/runoff, land sliding, droughts, MAH loads/evaporation, infrastructure availability, strong winds, snow loads, water quality deterioration, power outage (new design standards)

KPI Framework Development (ongoing)

Implications	Water	Energy (non-renewable)	Scope 3 (chemicals and more)	Emissions (beyond C) – both air and liquid
Impact	Depleting Watershed by evaporation	C emission	C emission	Using energy to control
	Load on the external infrastructure	Load on the external infrastructure	Using water and other natural resources	Health impact
		Use of natural resources to produce	Other emissions	Ecological impact (climate, other life)
Commonality	Energy seems to be a common denominator for all			
Considerations for KPI	Energy to restore, deliver, and purify Recommend excluding infrastructure consideration, implying solution is a part of the business fundamentals	Direct correlation	Consider only those elements of the scope that result in trade-offs (major chems – primary); Energy to produce and deliver	Energy to treat and dispose

KPI Framework, initial ideas

$$KPI=x*W_{(H2O)} + y*C_{(Chems)} + z*E_{(energy)} + n*WW_{(waste,\ wastewater,\ air\ polution)}$$

- “Plus” sign is recommended because each one of the components of the framework may become “0”
- Effect of the water and CO2 credit is pending resolution of Task 1. If applicable and credits exist, the factors may become “0”.
- Each factor is the function of the relative importance due to site specific conditions.
- Consider CO2 equivalent as common denominator for all factors
  - Water – energy to “produce” and deliver
  - Energy – CO2 equivalent (unless carbon credits are acceptable)
  - Chemicals – energy (CO2) to produce
  - Wastewater, waste, air pollution
    - Energy to treat and dispose
    - Other emissions – CO2 equivalent to produce the same global warming effect (hazard elimination for compliance is implied

EU PFAS Restriction Update

1 **13 January 2023**
Restriction proposal submitted to ECHA

2 **7 February 2023**
Proposal made available on ECHA's website

3 **22 March 2023**
Start of a six-month open consultation

4 **5 April 2023**
Online information session

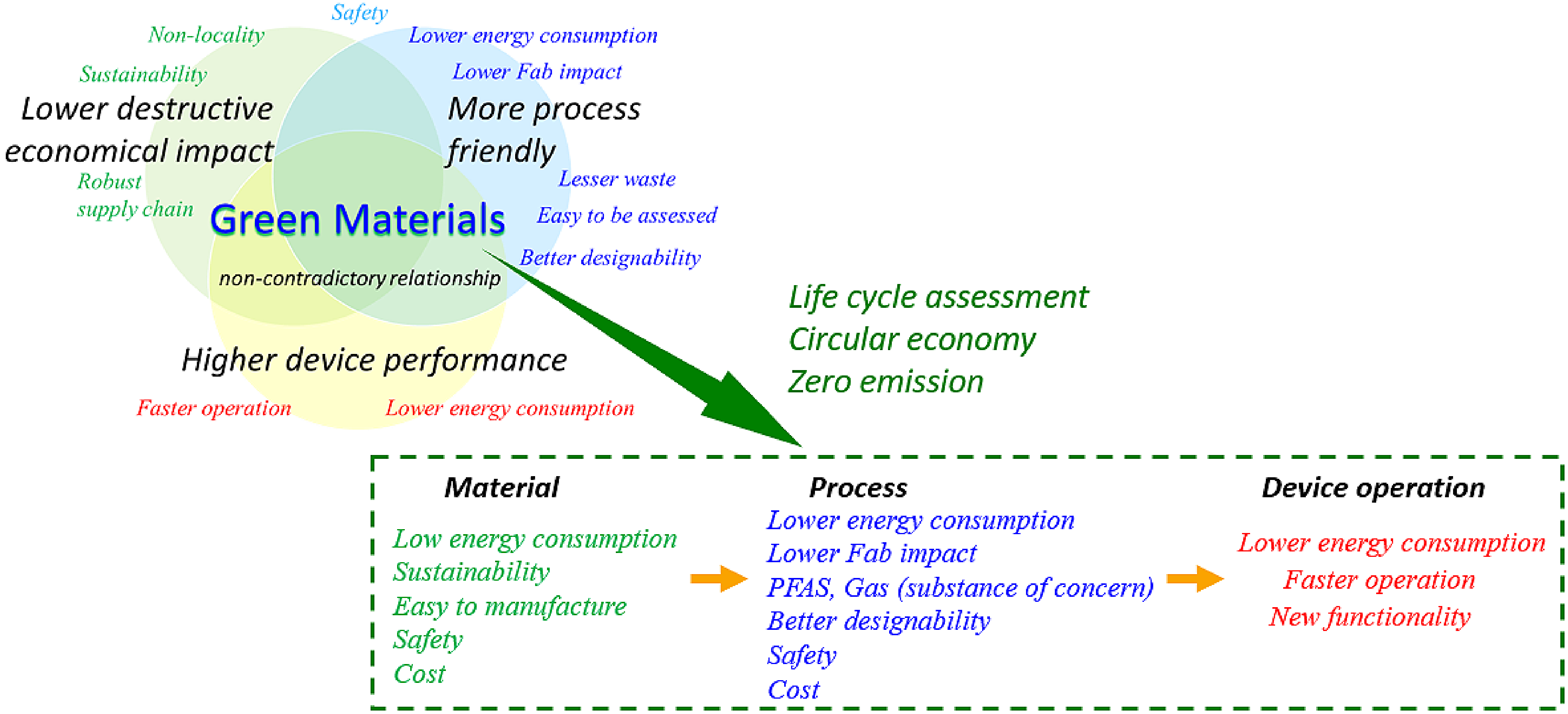
5 ECHA committees' evaluation

6 ECHA's committees adopt their opinions

7 Opinions of ECHA's committees sent to the European Commission

- Five member countries, Denmark, Germany, the Netherlands, Norway and Sweden, submitted a proposal to ECHA (European Chemicals Agency) to restrict per- and polyfluoroalkyl substances (PFASs) under REACH, the European Union's (EU) chemicals regulation.
- ECHA will publish the detailed proposal, one of the broadest in the EU's history, on 7 February 2023.
- Six-month consultation begins on 22 March.
- SIA PFAS consortium will have white papers and socioeconomic reports ready for consultation period.

Perspective on materials design strategies (Japan)



Safety

Non-locality

Sustainability

Lower destructive economical impact

Robust supply chain

Lower energy consumption

Lower Fab impact

More process friendly

Lesser waste

Easy to be assessed

Better designability

Green Materials

non-contradictory relationship

Higher device performance

Faster operation

Lower energy consumption

Life cycle assessment
Circular economy
Zero emission

Material	Process	Device operation
Low energy consumption Sustainability Easy to manufacture Safety Cost	Lower energy consumption Lower Fab impact PFAS, Gas (substance of concern) Better designability Safety Cost	Lower energy consumption Faster operation New functionality

GC Principles applied to the SC/Electronics Industries

- **Prevention:**
  It is better to prevent waste than to treat or clean up waste after it has been created.
  - Technology road-mapping, Environmental technology goal setting, materials re-use
- **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.
  - Energy efficient vacuum pumps, applying AI and machine learning to minimize process energy usage
- **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
  - Chemical replacement projects, design focus on ww, air emission reuse, reclaim
- **Atom Economy**
  Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
  - Materials usage efficiency, total COO tool
- **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
  - Exploring how to integrate green chemistry across the technology life cycle, supplier collaboration on GC/E systems
- **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
  - Defining future metrology needs through the technology roadmap process, use of chemical sensing, software to actively manage waste treatment, collection/reuse and recycling

OUR COMMITMENT TO SUSTAINABILITY

SRC will drive an R&D agenda that delivers **greener materials and processes** for semiconductor manufacturing, creates chips and packages with **radically improved energy efficiency**, and drives a revolution in the efficiency of future information and communication technology systems **at scale.**

READ MORE AT SRC.ORG/SUSTAINABILITY

SRC’s ESH History

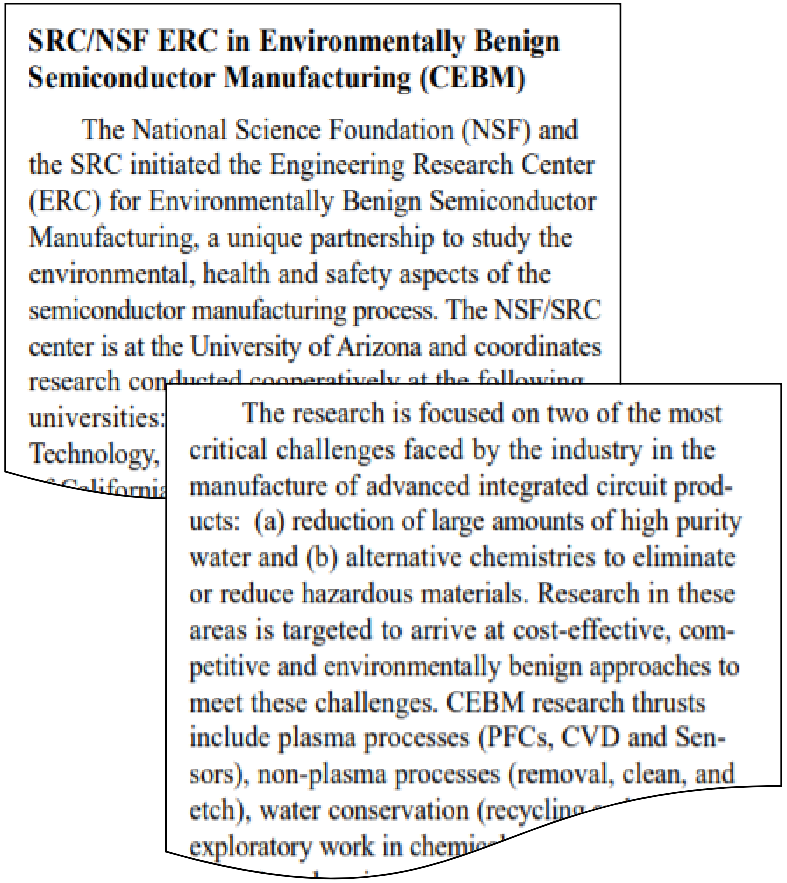
- Started in 1994 with ~10 tasks, **$0.9M/yr.**

➢ **In 1996, commenced long relationship led by U/Arizona & Prof. Farhang Shadman**

- 1996 - $10.8M (**$2.2M/yr.**) – *CEBM* Center - NSF & SRC
- 2001 - $41.4M (**$2.5M/yr.**) – ERC on *Environmentally Benign Semiconductor Manufacturing* – NSF, SRC, Sematech, plus 19 Companies, Universities, and Affiliates
- 2008 - $2.5M (**$0.8M/yr.**) – *Nanoparticles* - SRC, Intel, Universities
- 2018 - $3.5M (**$0.9M/yr.**) – *Onium* - SRC, SIA, Intel, Universities

- Majority of research scope tied to patterning since it was the industry and technology driver.

1996 Annual Report



SRC/NSF ERC in Environmentally Benign Semiconductor Manufacturing (CEBM)

The National Science Foundation (NSF) and the SRC initiated the Engineering Research Center (ERC) for Environmentally Benign Semiconductor Manufacturing, a unique partnership to study the environmental, health and safety aspects of the semiconductor manufacturing process. The NSF/SRC center is at the University of Arizona and coordinates research con

universities:

Technology,

The research is focused on two of the most critical challenges faced by the industry in the manufacture of advanced integrated circuit products: (a) reduction of large amounts of high purity water and (b) alternative chemistries to eliminate or reduce hazardous materials. Research in these areas is targeted to arrive at cost-effective, competitive and environmentally benign approaches to meet these challenges. CEBM research thrusts include plasma processes (PFCs, CVD and Sensors), non-plasma processes (removal, clean, and etch), water conservation (recycling

exploratory work in chemi

- *Reduction of high purity water*
- *Alternative chemistries that eliminate or reduce hazardous materials*

High-Level ESH/S Objectives and Goals

Aligned to both Microelectronics and Advanced Packaging Technologies as the Drivers

- Reduction <u>and return</u> of high purity water
- Alternative chemistries that eliminate or reduce hazardous materials or pose environmental and human health risk.
- Growing emphasis on understanding and removal of Per- and Polyfluoroalkyl Substances (PFAS)
- Treatment and abatement technologies for effluent, emission, and waste management
- Improvement of processes and systems to reduce energy and material use and minimize waste generation

NIST Manufacturing USA Technology Roadmap

Letters of Support included in SRC's Proposal

CISCO

MOSAIC microsystems

IBM

arm

TEL TOKYO ELECTRON

NXP

AMD

GlobalFoundries™

OXFORD INSTRUMENTS

MEDIATEK

Tower Semiconductor

APPLIED MATERIALS

CIRRUS LOGIC

ASE GROUP

CORNING

IPC

ANALOG DEVICES

iNEMI International Electronics Manufacturing Initiative

XILINX

intel

Sandia National Laboratories

Micron

TEXAS INSTRUMENTS

Pacific Northwest NATIONAL LABORATORY

IEEE COMPUTER SOCIETY

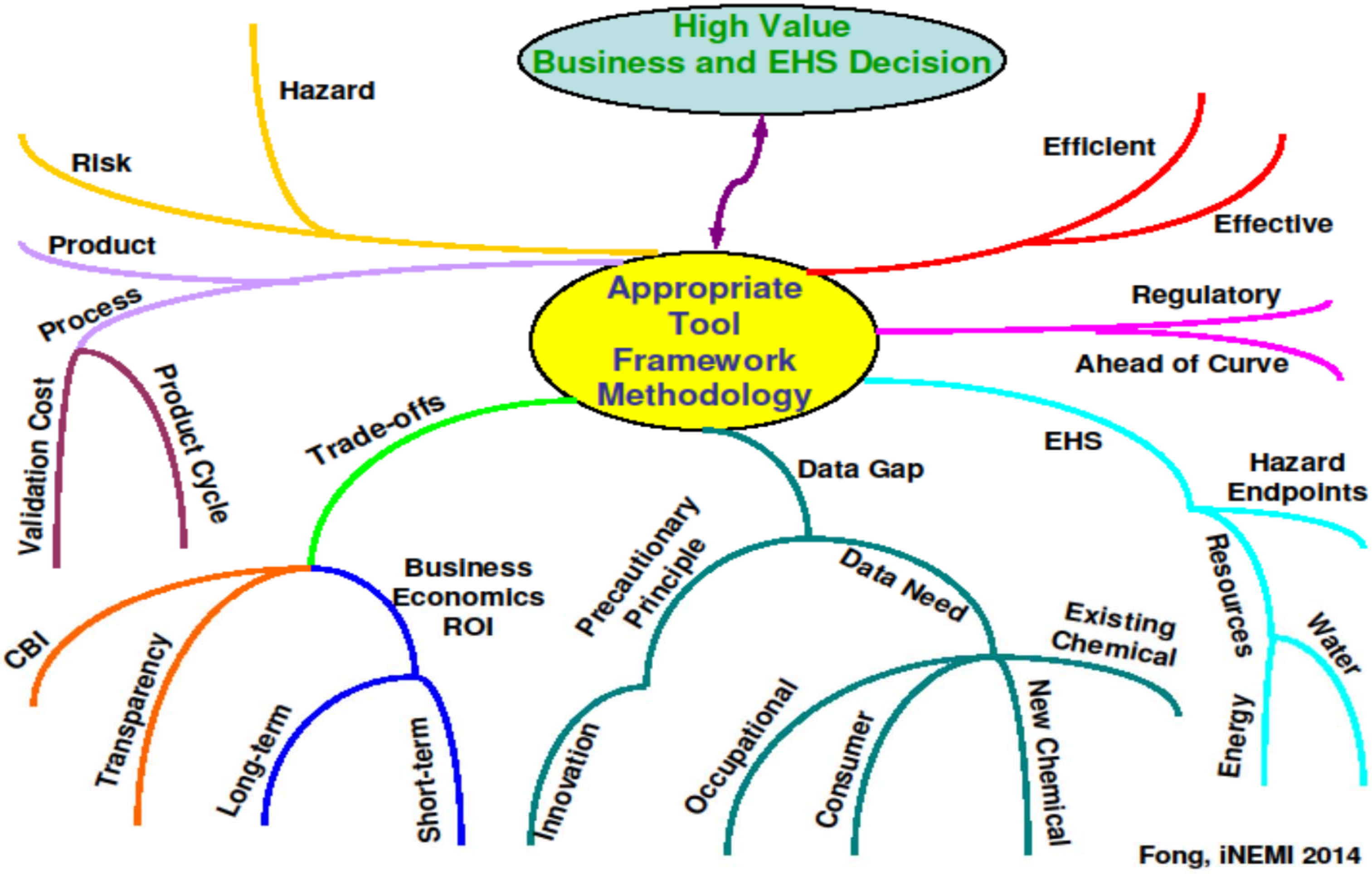
IEEE

IEEE rebooting COMPUTING

IEEE COMPUTER SOCIETY TFRC Task Force on Rebooting Computing

IRDS

Considerations in assessing ESH/S impacts for mataterials design and selection



Fong, iNEMI 2014