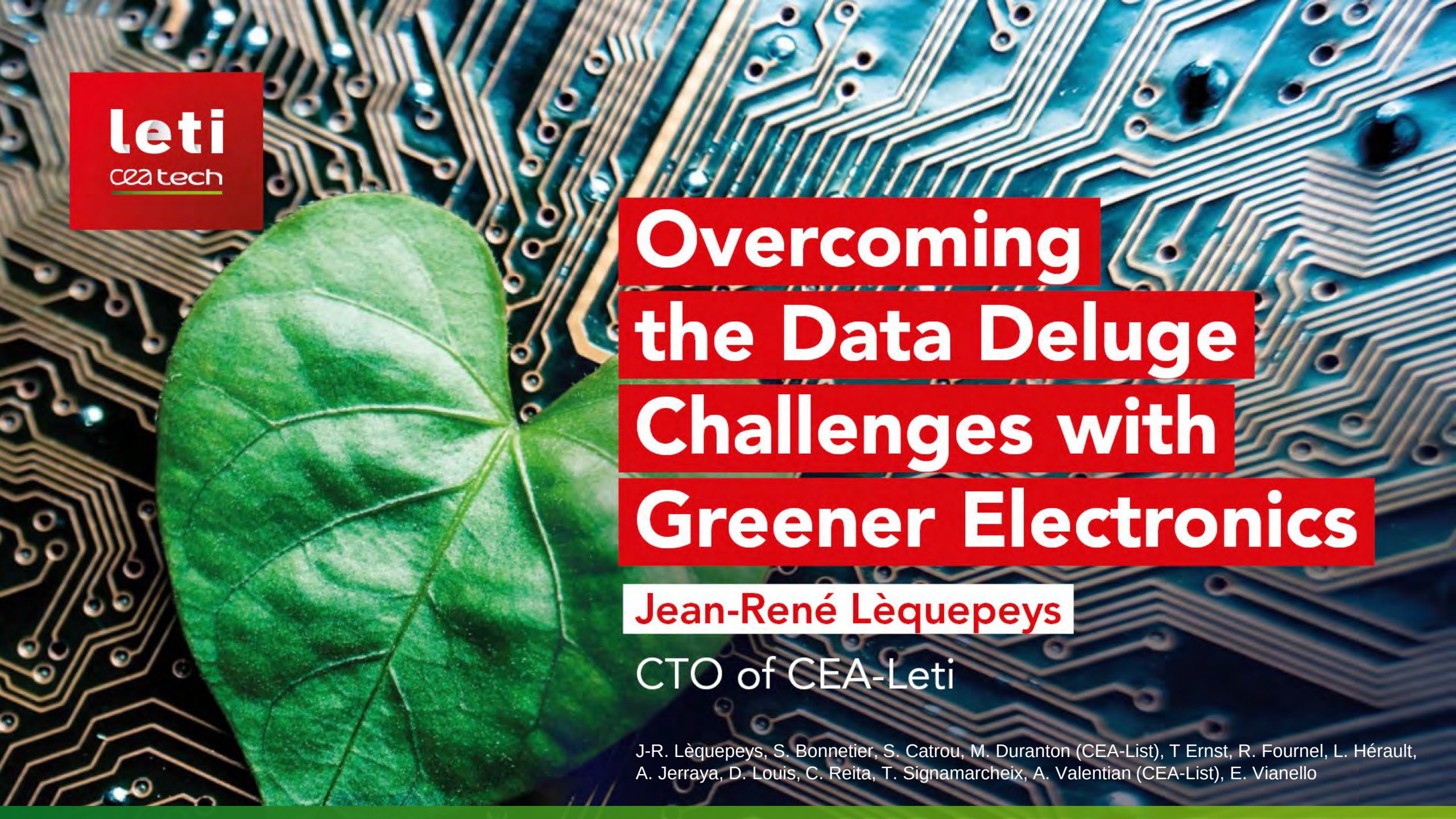


leti
cea tech

Overcoming the Data Deluge Challenges with Greener Electronics

Jean-René Lèquepeys

CTO of CEA-Leti

J-R. Lèquepeys, S. Bonnetier, S. Catrou, M. Duranton (CEA-List), T Ernst, R. Fournel, L. Hérault, A. Jerraya, D. Louis, C. Reita, T. Signamarcheix, A. Valentian (CEA-List), E. Vianello

FACING GLOBAL DIGITALIZATION

Digitalization is accelerating and bringing new useful services

Major show-stoppers:

- **Energy efficiency**
- **Sustainable electronics**

Breakthrough innovations are necessary:

- In Semiconductor technologies
- In Circuits and architectures
- In Systems, usage and practices

OUTLINE

Context

The unstoppable trend:
Data deluge

Challenge

An urgent need for:
Environmental sustainability

Vision

Greener electronics: 9 research tracks
to harvest the full potential of digitalization

Outlook

Effect on the
Semiconductor research agenda

CONTEXT

THE IRREVERSIBLE TRENDS: DATA DELUGE & HIGHER ENERGY DEMAND

2010-2020:

› A data-driven era

Internet users

+125%

World population

+10%

Mobile data

+20316%

Internet traffic

+1170%

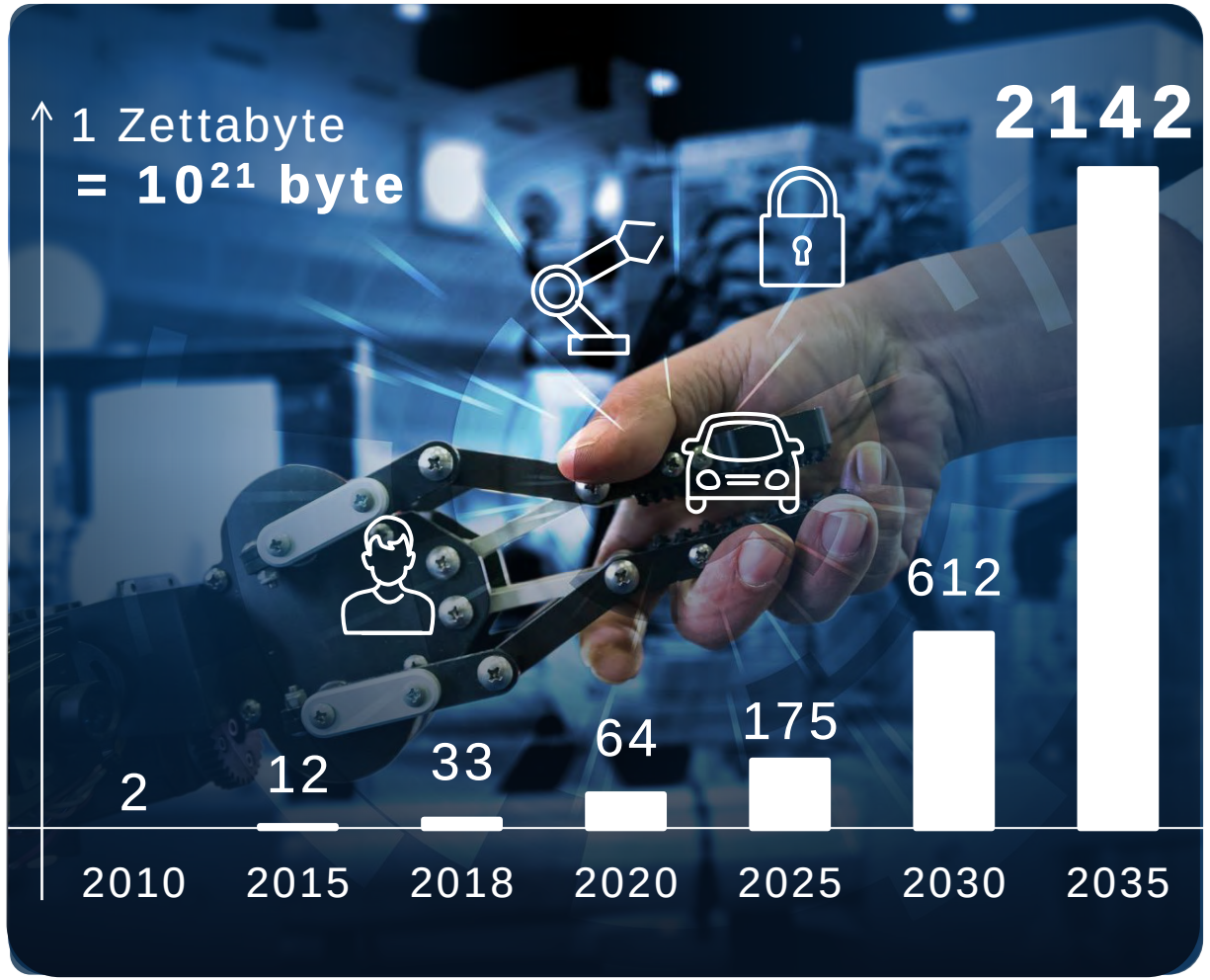
Electricity

+22%

Sources: Worldometers 2021, enerdata 2021, ourworldindata.org
Internet 2021, Cisco Visual Networking Index 2011 & 2020, Ericsson Mobility report 2021

DATA GENERATION

› Machines are overtaking humans



In 2018, 44% of the total data was generated by machines

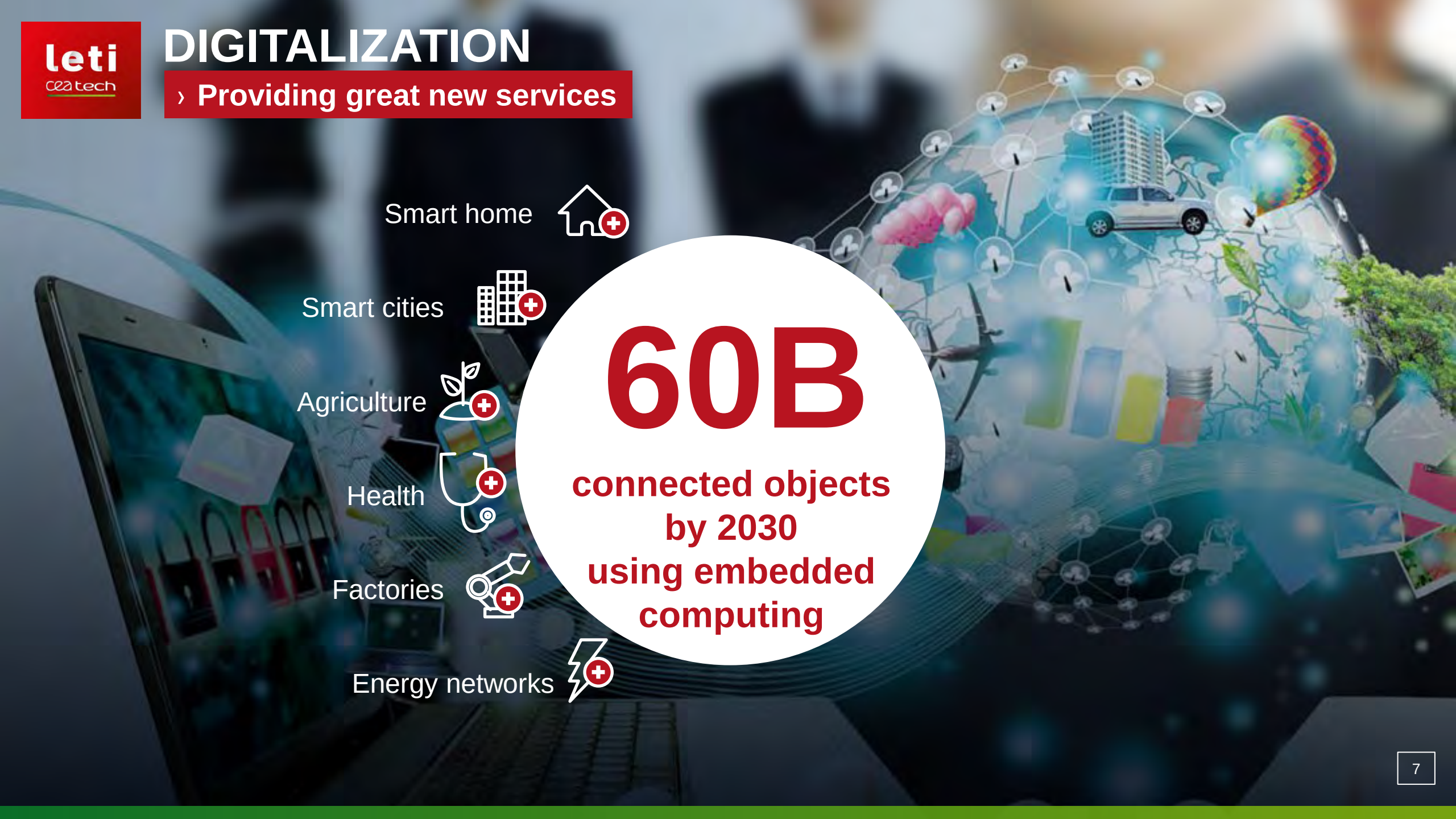
In 2022,

90%

will be generated by machines

DIGITALIZATION

› Providing great new services



DIGITALIZATION

› Providing great new services

Smart home

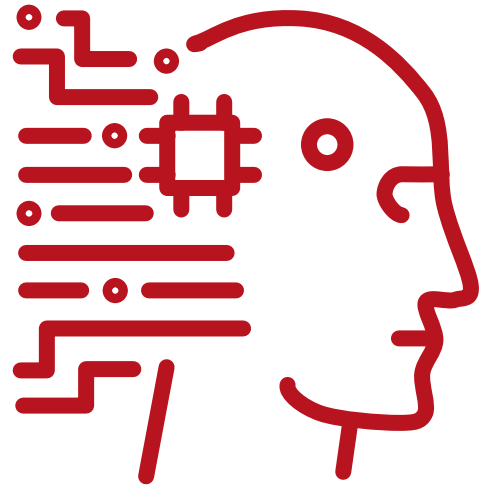
Smart cities

Agriculture

Health

Factories

Energy networks

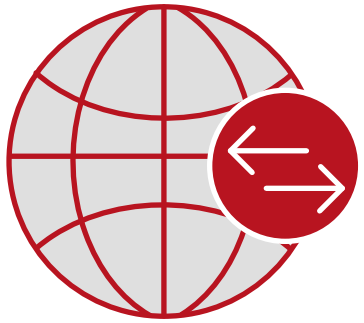


IoT, embedded AI and digital twins will help:

- Run factories and optimize raw materials and energy usage
- Manage decentralized and intermittent energy production
- Design new materials and new medication
- And more

DATA MANAGEMENT:

› Computing plays a key role



Transmission to processing units

Storage and processing

Exploitation

By 2025, over 50% of the data will be real-time

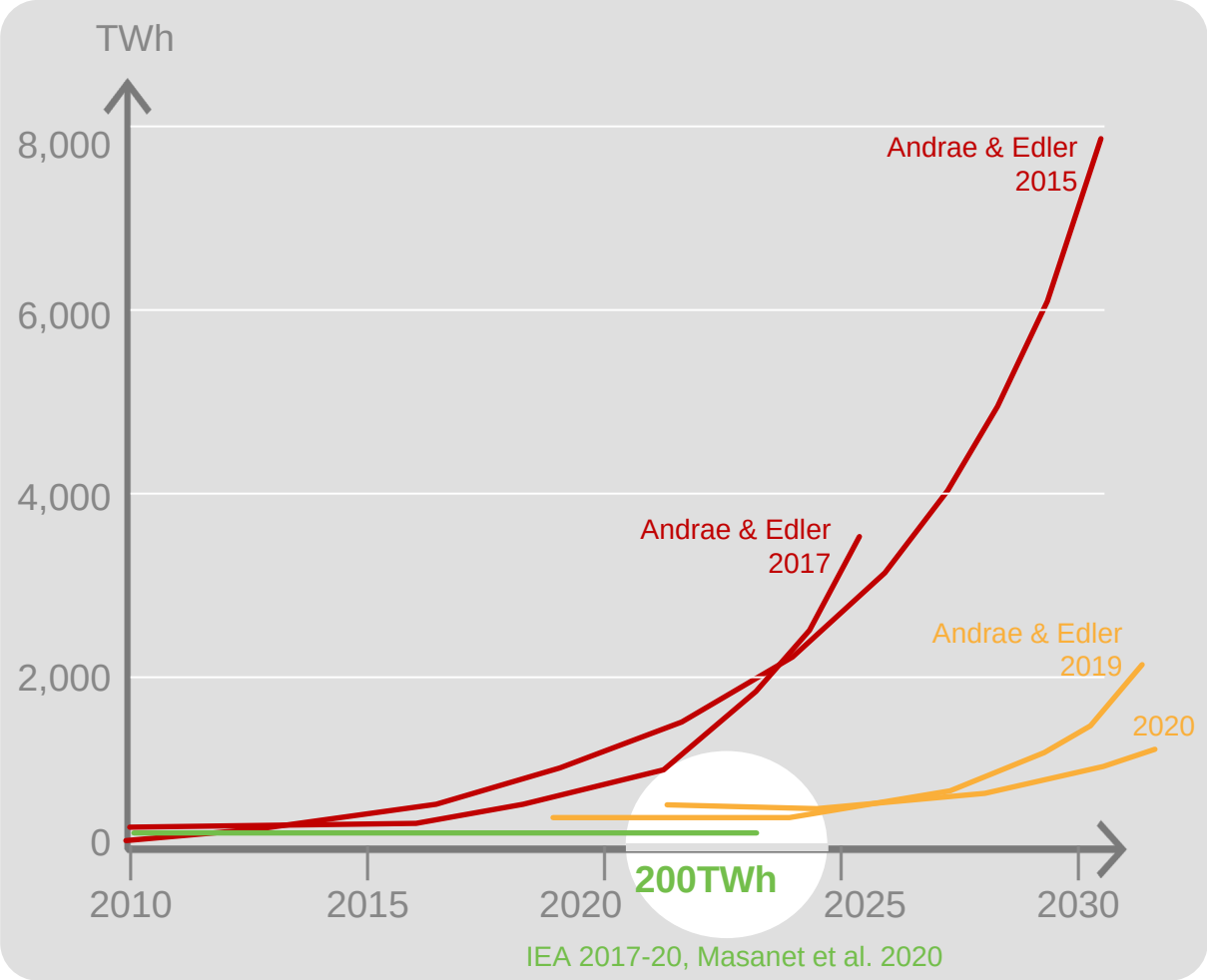
→ **local processing is needed**

CHALLENGE

INNOVATION WILL BE KEY FOR ENVIRONMENTAL SUSTAINABILITY

DATA CENTERS

› Energy consumption scenarios



IEA 2017-20, Masanet et al. 2020

The energy footprint of datacenters is stable so far, thanks to constant innovation

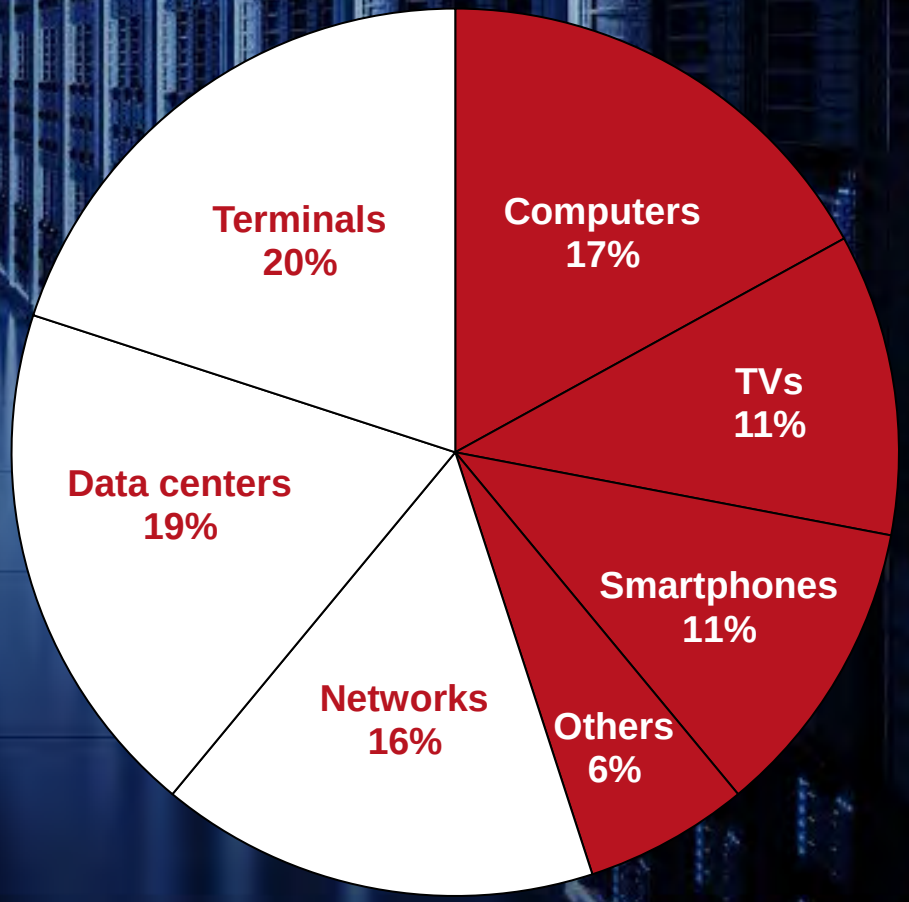
› The focus is on CPU & Memory optimization to further improve energy efficiency

ELECTRONIC DEVICES

› Where is the energy consumed?

55%

of the energy is consumed by **using** the devices

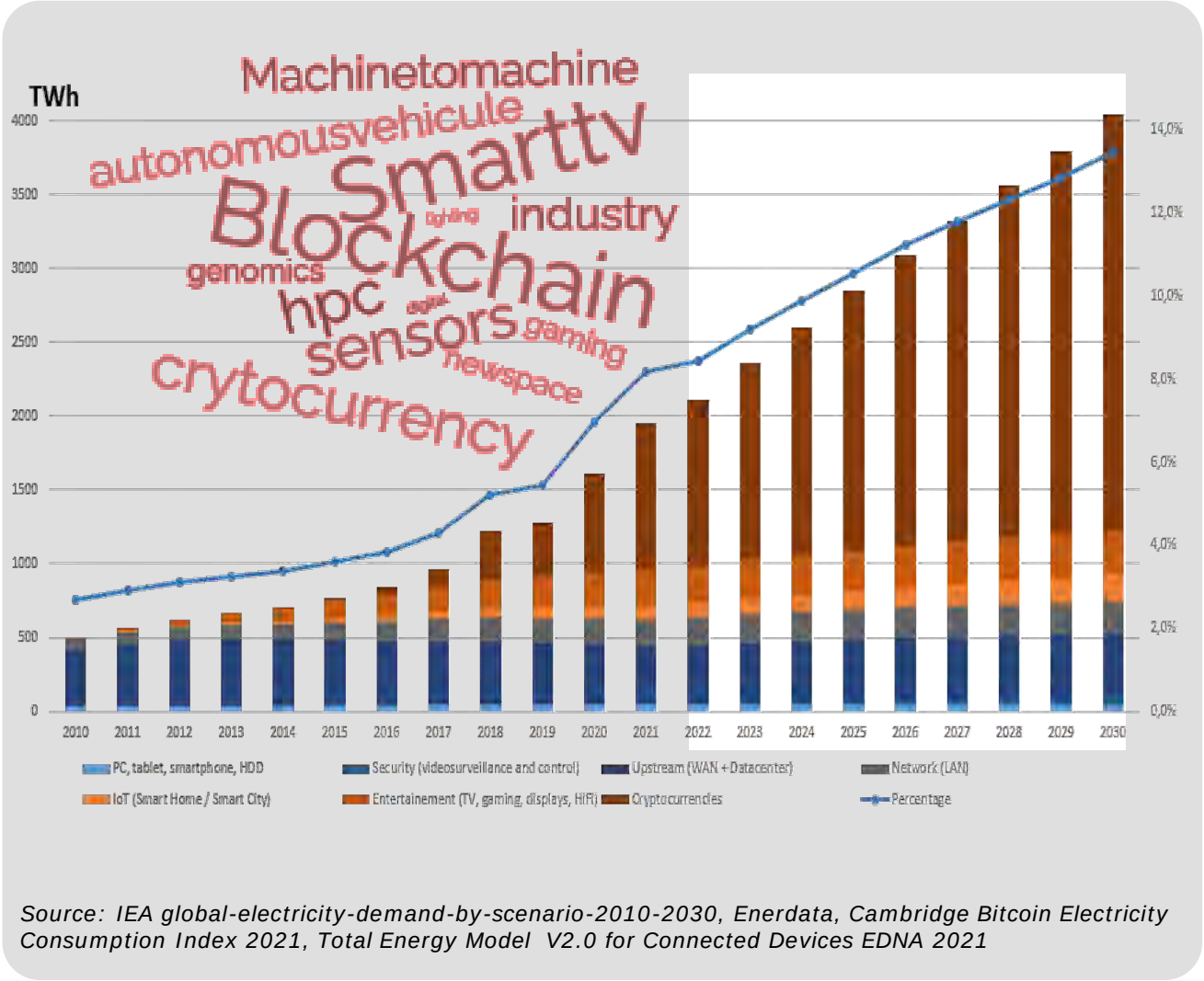


45%

of the energy is consumed during **production**

Source: the Shift Project 2018

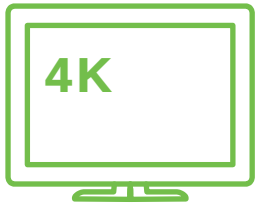
TOMORROW'S COMPUTING CHALLENGES



Source: IEA global-electricity-demand-by-scenario-2010-2030, Enerdata, Cambridge Bitcoin Electricity Consumption Index 2021, Total Energy Model V2.0 for Connected Devices EDNA 2021

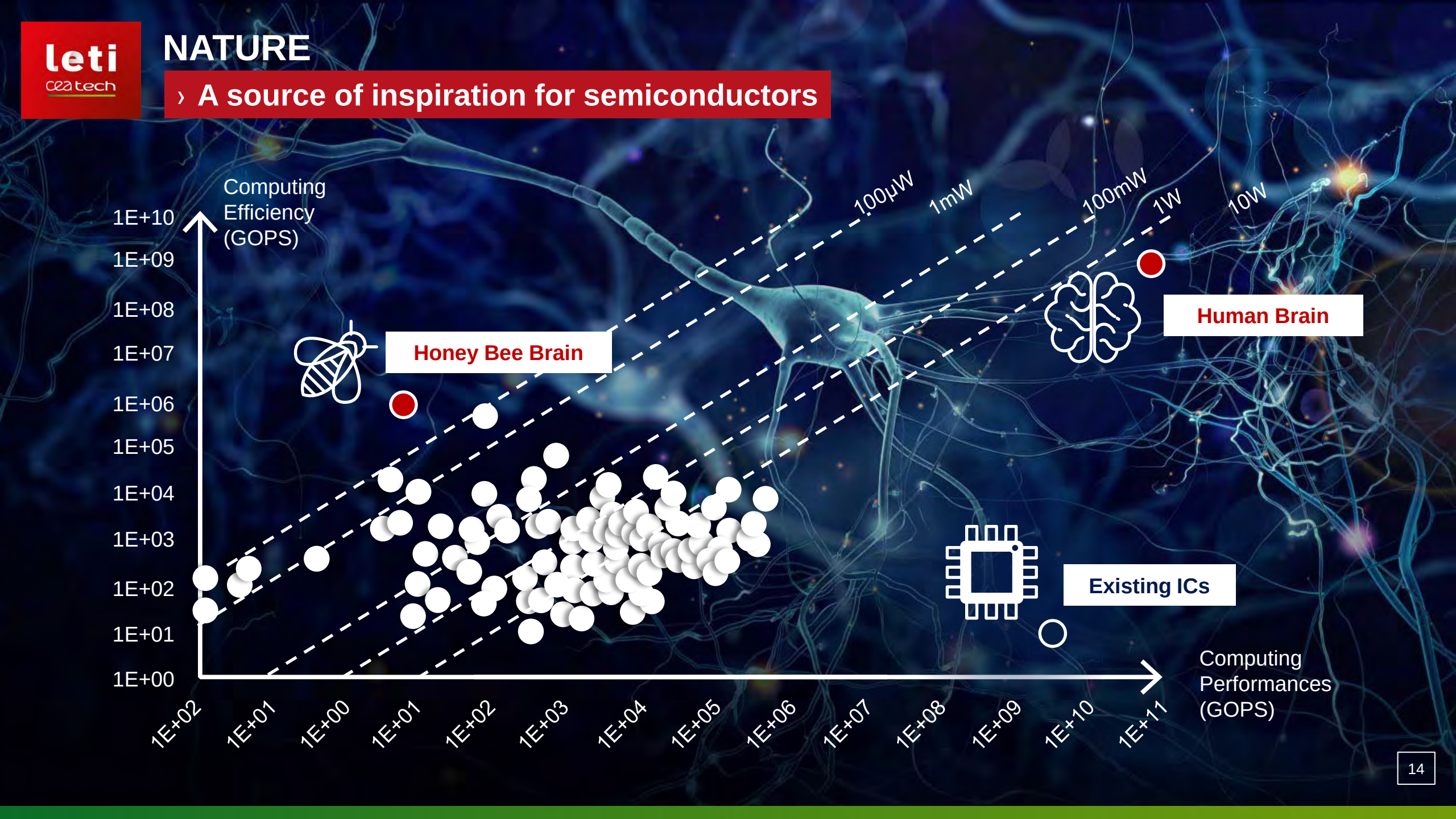
A new data tsunami?

› 14% of the global electricity demand



NATURE

› A source of inspiration for semiconductors



Deterioration of ecosystems and living conditions,

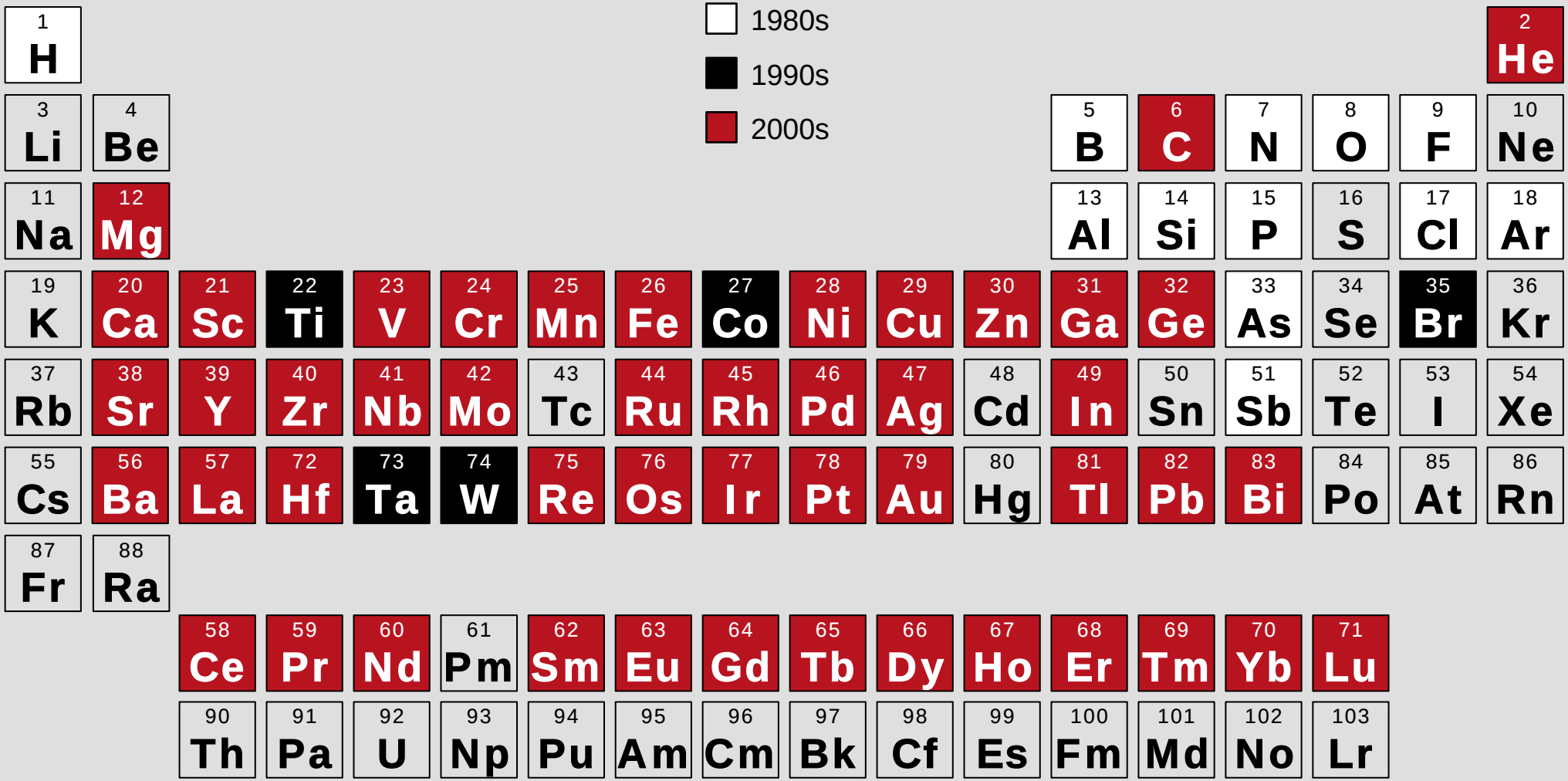
increasing amounts of rare earths and minerals

that are difficult to recycle

We must find alternatives

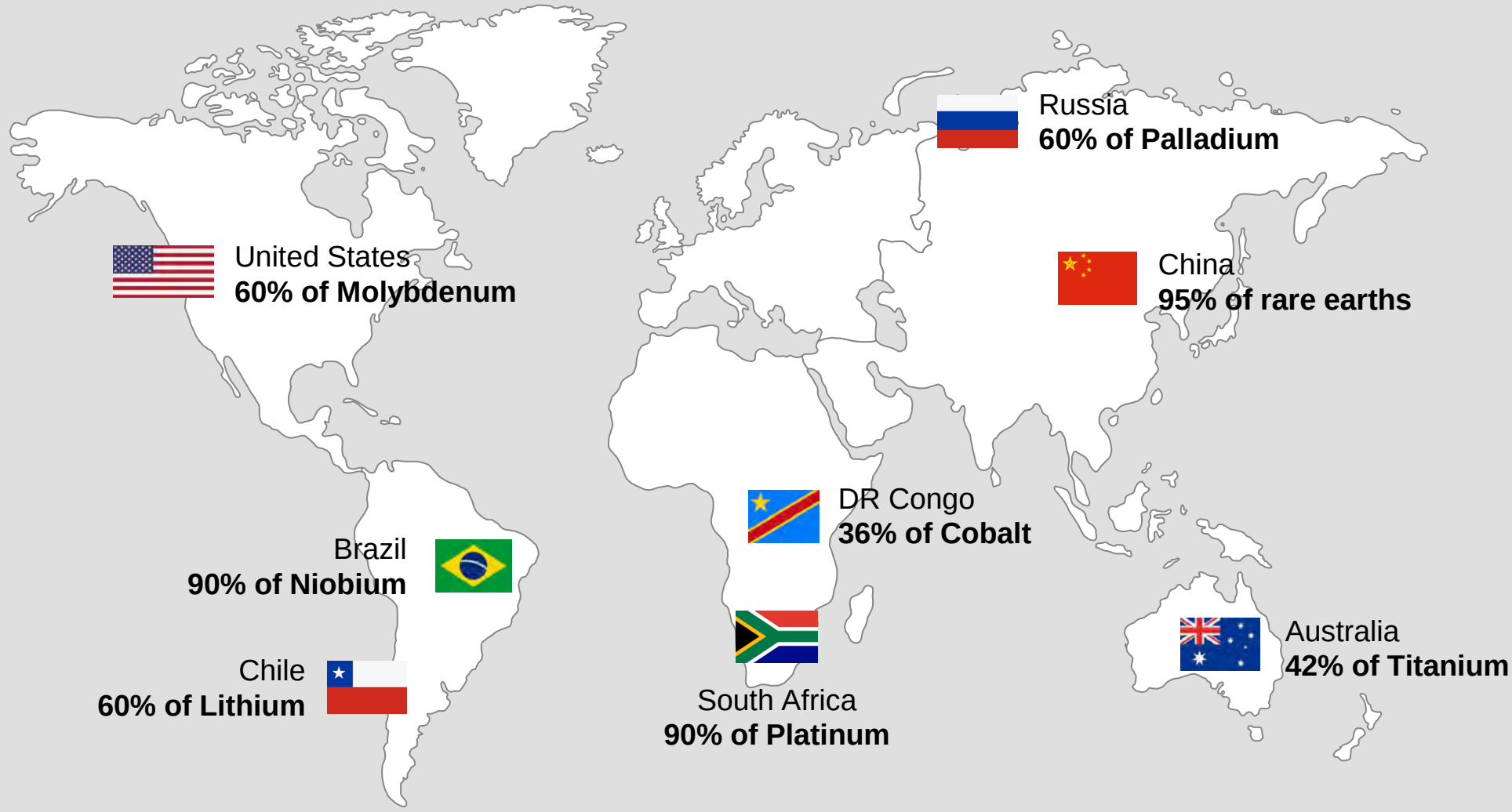
ICT INDUSTRY:

› 60 elements are used, less than 15% is recycled



RARE EARTHS AND MINERALS

› A small number of countries control the production




CEA-Leti recommends
9 research tracks
to manage the data deluge and achieve
the energy efficiency that society will demand

9 RESEARCH TRACKS

Improve energy efficiency

×1000

	Now, Short term 2-3 years	Medium term 3-5 years	Long term 5-10 years
Semi-conductors	**NVM for neuromorphic chips**	**3D monolithic, GAA, FD-SOI**	**Quantum computing CMOS qubits**
Circuits & architecture	**Active silicon interposers & chiplets**	**Dedicated versatile accelerators**	**ASIC + AI solutions to move less data**
Systems, usage & practices	**Edge computing solutions**	**New algorithms**	**Sustainable electronics**

CEA-LETI

› Technology research institute

Created in **1967** in Grenoble, France

2,000 people in 2021

3,000+ patents in portfolio

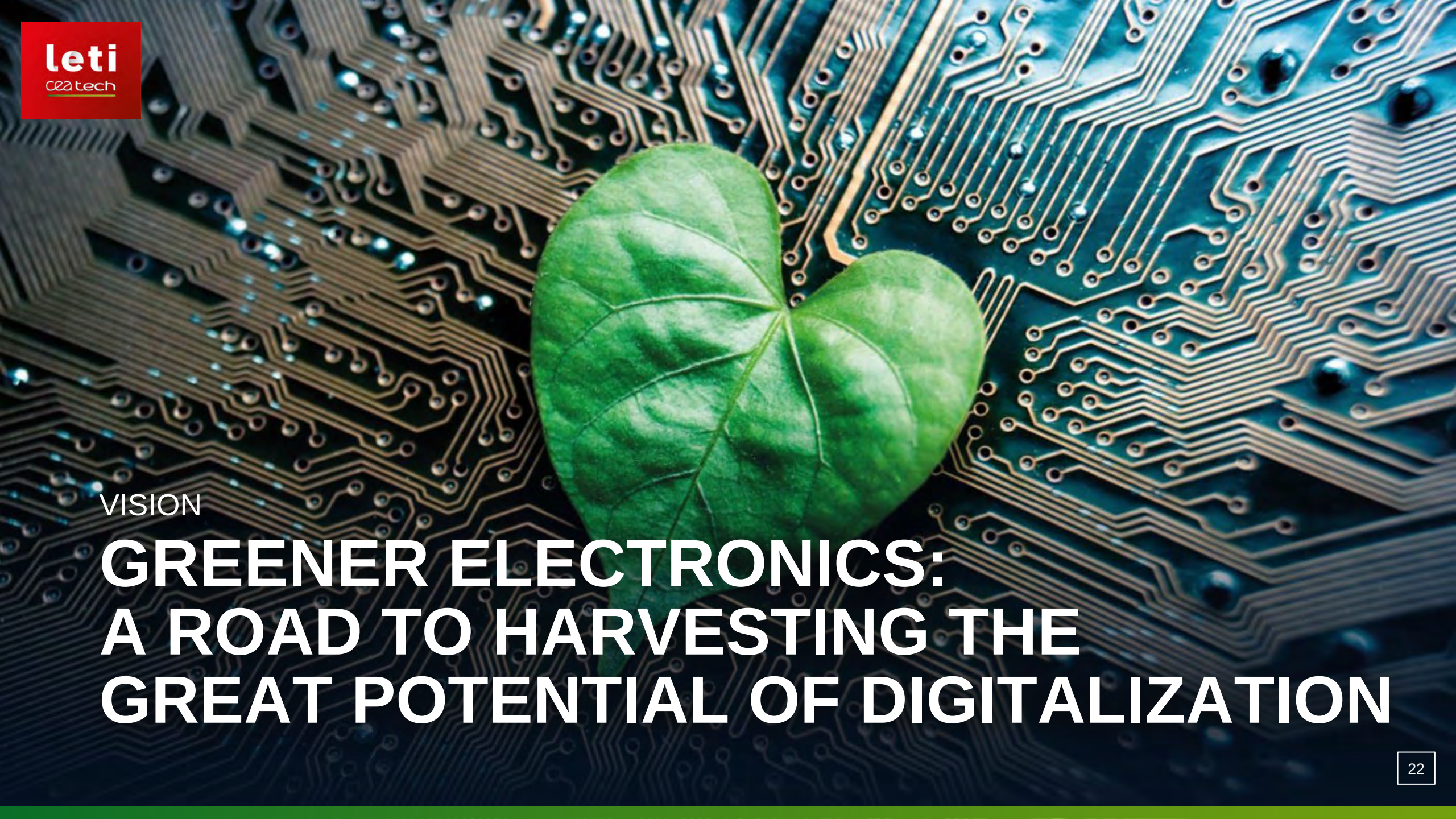
72 startups created over 20 years

3,500 new jobs

600 state-of-the-art tools

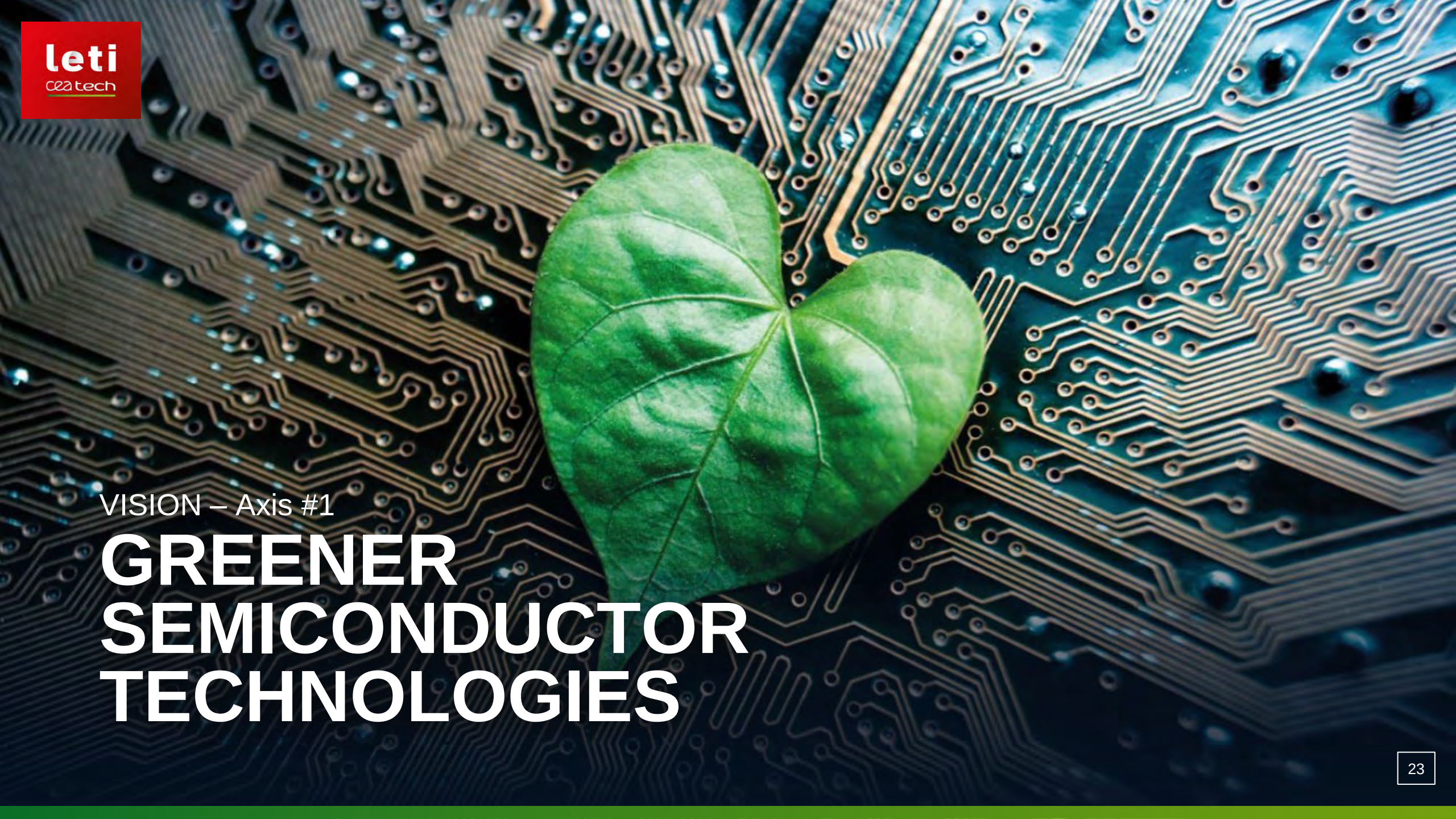
11,000 m² of cleanroom space


Committed to innovation,
CEA-Leti's dedicated teams
pioneer micro-nanotechnologies
enabling smart, energy-efficient
and secure solutions for industry



VISION

GREENER ELECTRONICS: A ROAD TO HARVESTING THE GREAT POTENTIAL OF DIGITALIZATION



VISION – Axis #1

GREENER SEMICONDUCTOR TECHNOLOGIES

9 RESEARCH TRACKS

› Improve energy efficiency ×1000

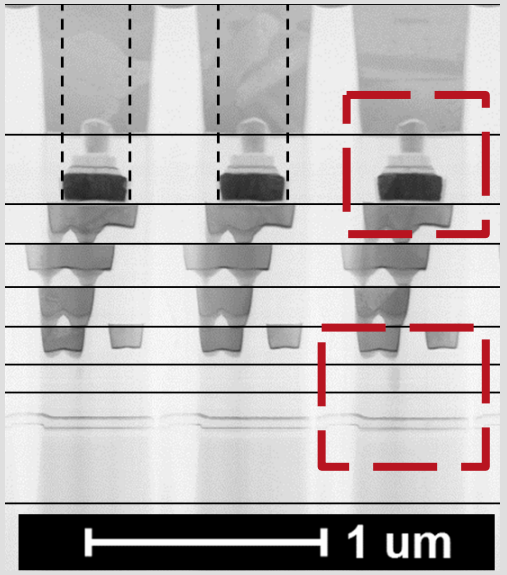
MEMORY IS CRITICAL TO MEET THE ENERGY CHALLENGE

How data consumes energy

Operation	Energy
Addition of data (fixed point)	1×
Accessing data (onchip cache)	60×
Accessing data (offchip RAM)	3500×

Data movement between storage and processing units can reach **90% of the overall energy consumption**

Non-volatile memories



Need for high density on-chip resistive memories

DIFFERENT TYPES OF MEMORIES

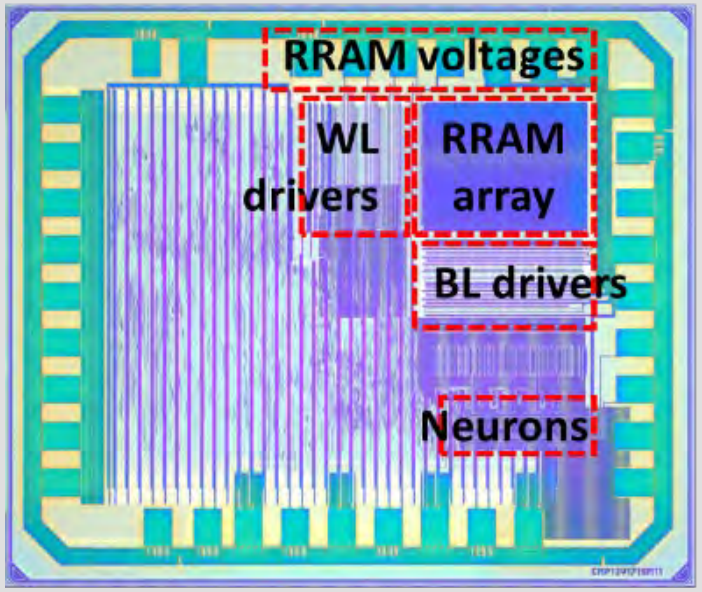
Programming power **reduction ×20,000**

	FLASH	ReRAM (HfO_2)	FeRAM (HfO_2)
Programming power	**~200pJ/bit**	~100pJ/bit	**~10fJ/bit**
Write speed	20 µs	10-100 ns	14ns @ 2.5V
Endurance	10^5 - 10^6	10^5 - 10^6	**> 10^{11}**
Retention	> 125°C	> 125°C	85°C
Extra masks	Very high (>10)	Low (2)	Low (2)

NEUROMORPHIC CHIPS

› Improve energy efficiency ×100+

SPIRIT



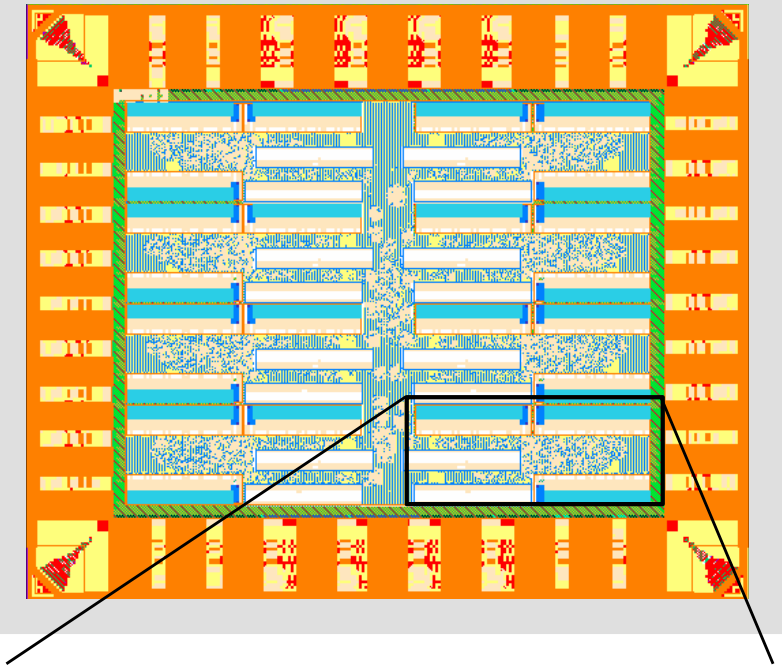
2019

CMOS node: 130nm

10 neurons & 144 synapses

3.6 pJ /spike

LARGO



CMOS node: 28nm FD-SOI

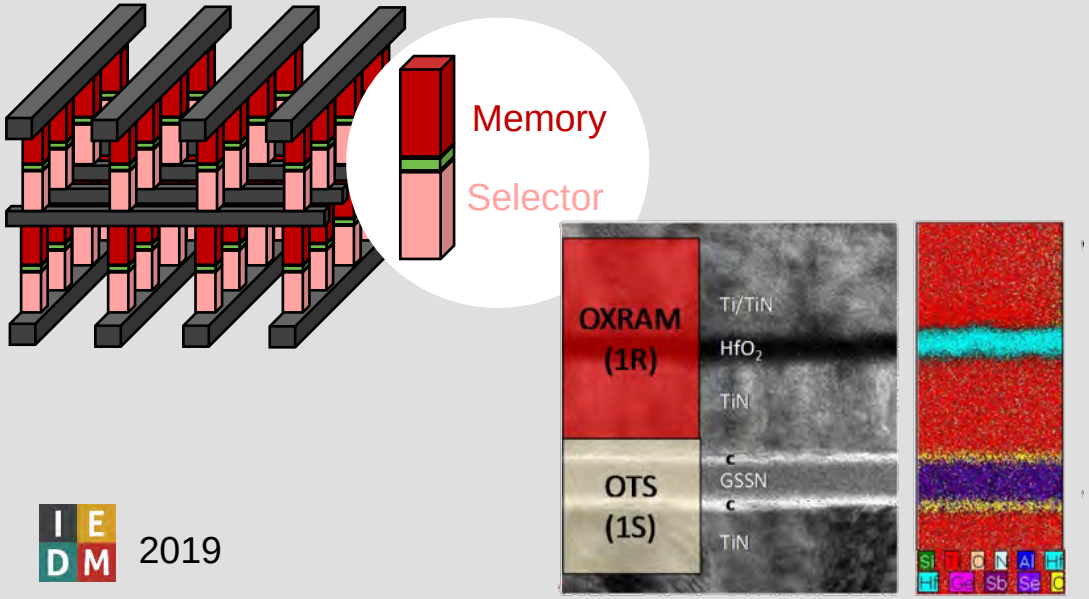
131k neurons & 75M synapses

0.5pJ / spike

NON-VOLATILE MEMORIES

› Increase density ×50

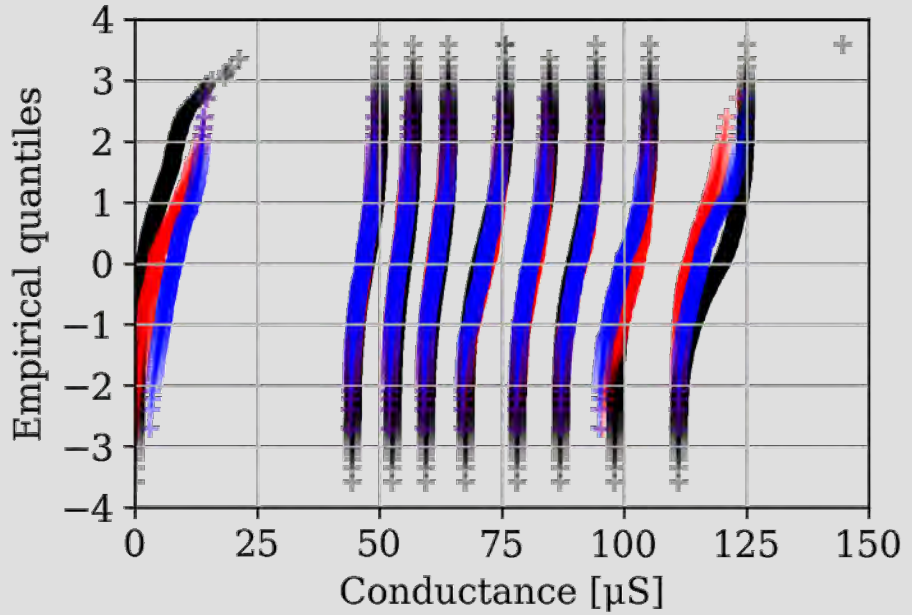
Ovonic Threshold Switch



IEDM 2019

Replacing transistors used to address the memory points

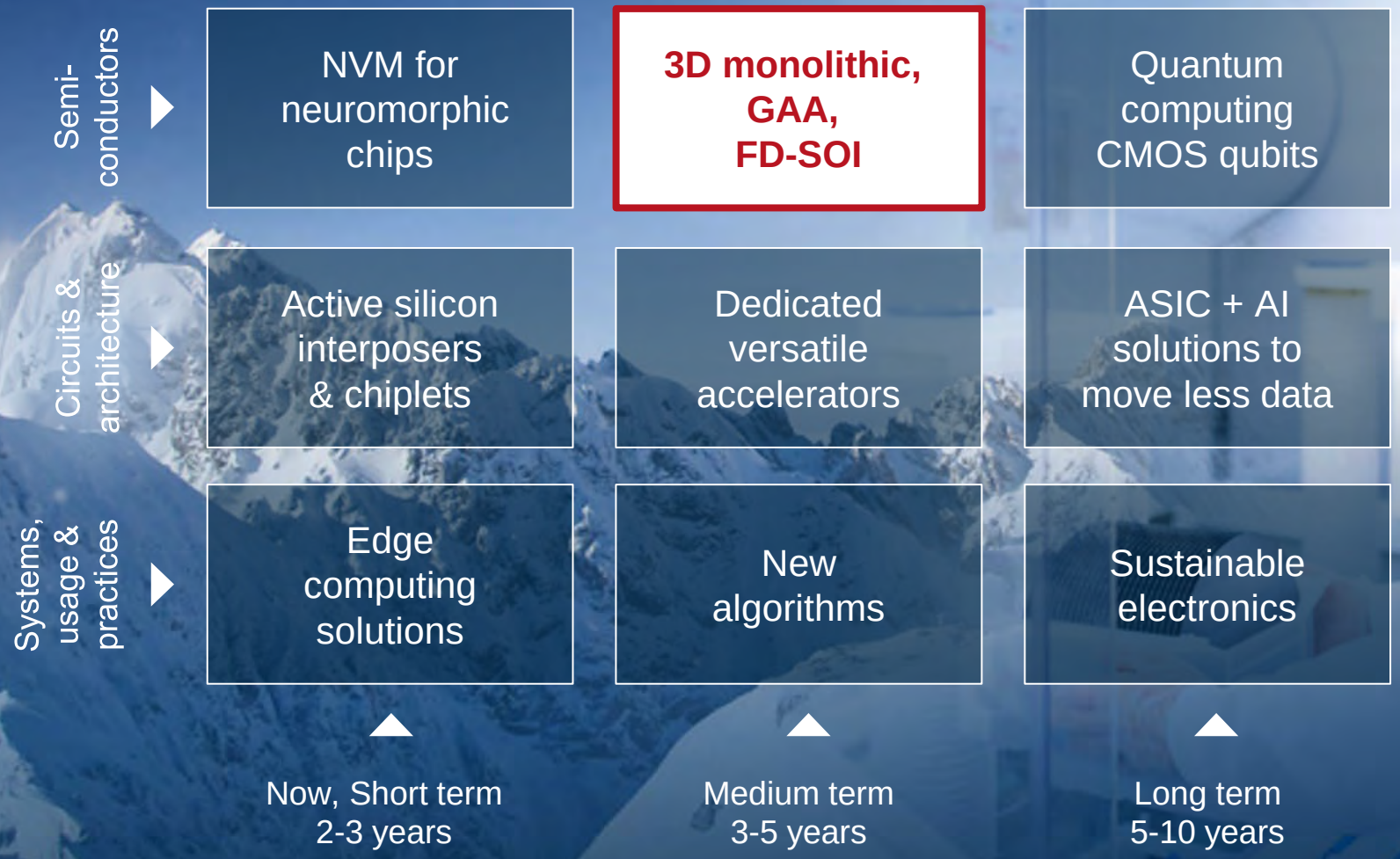
Multi-Level-Cell



3 bits per memory point

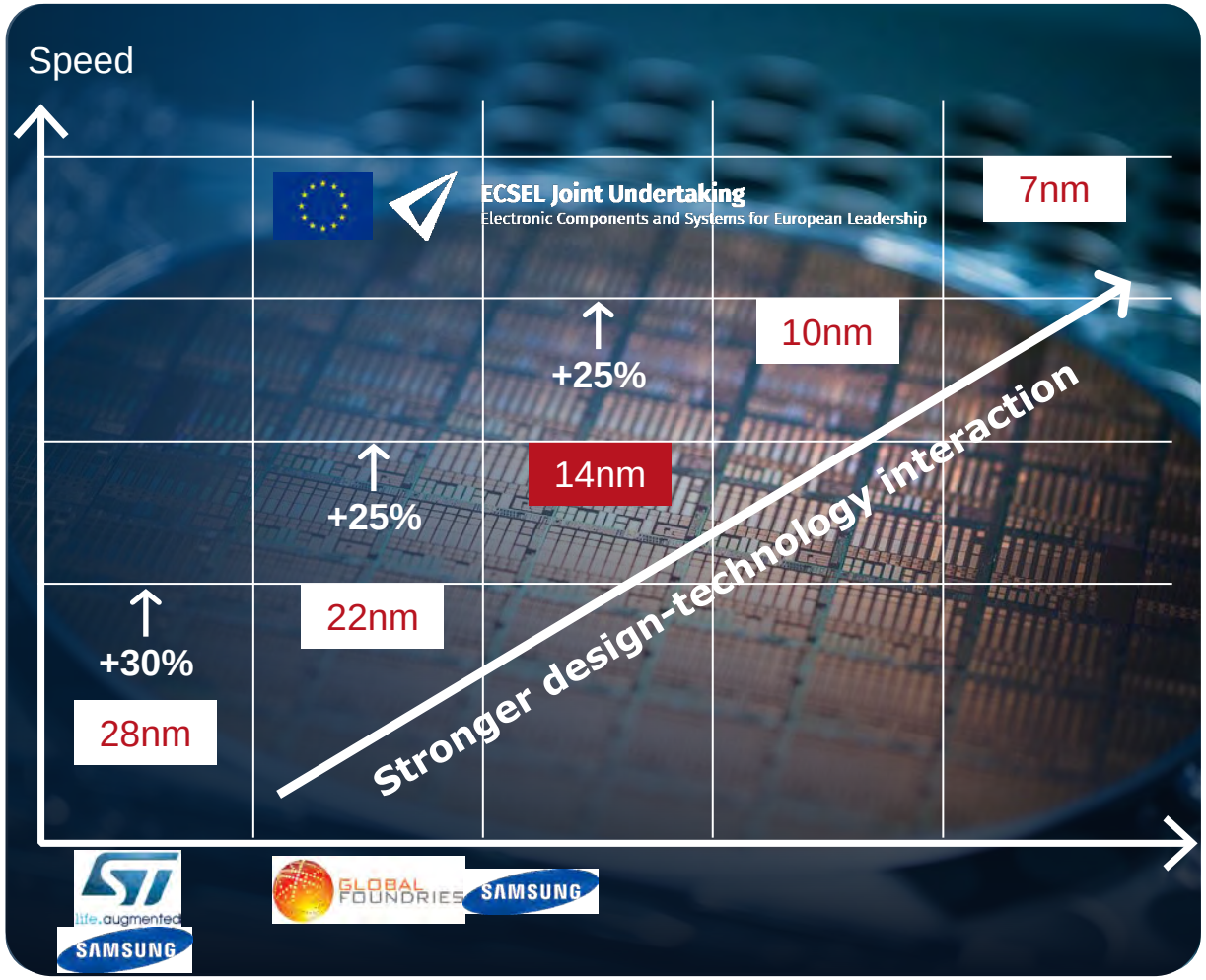
9 RESEARCH TRACKS

› Improve energy efficiency ×1000



FD-SOI ROADMAP

› Developing 14nm, 10nm and beyond nodes

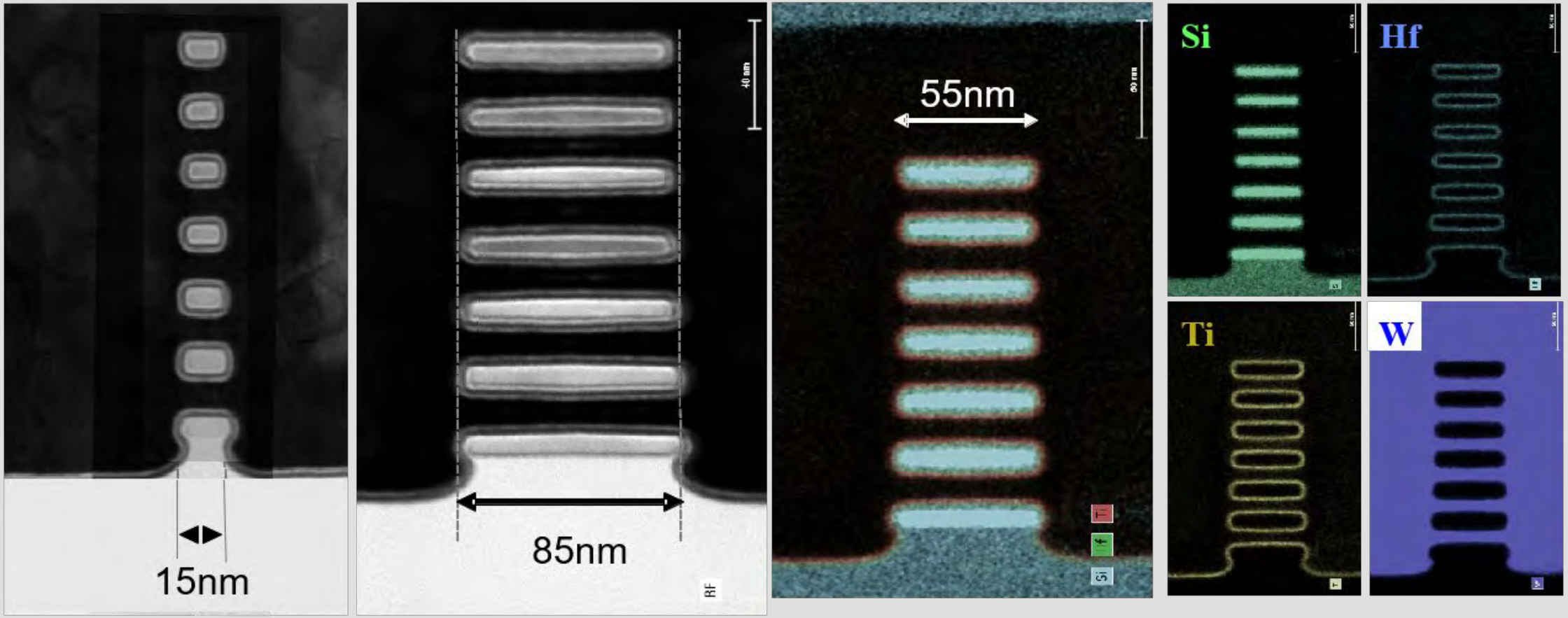


Scaling the FD-SOI technology is becoming indispensable

- ultra-low power IoT devices,
- automotive,
- RF,
- Edge AI,
- 5G-6G

SILICON-BASED DEVICES (GAA)

› Improve energy efficiency ×2

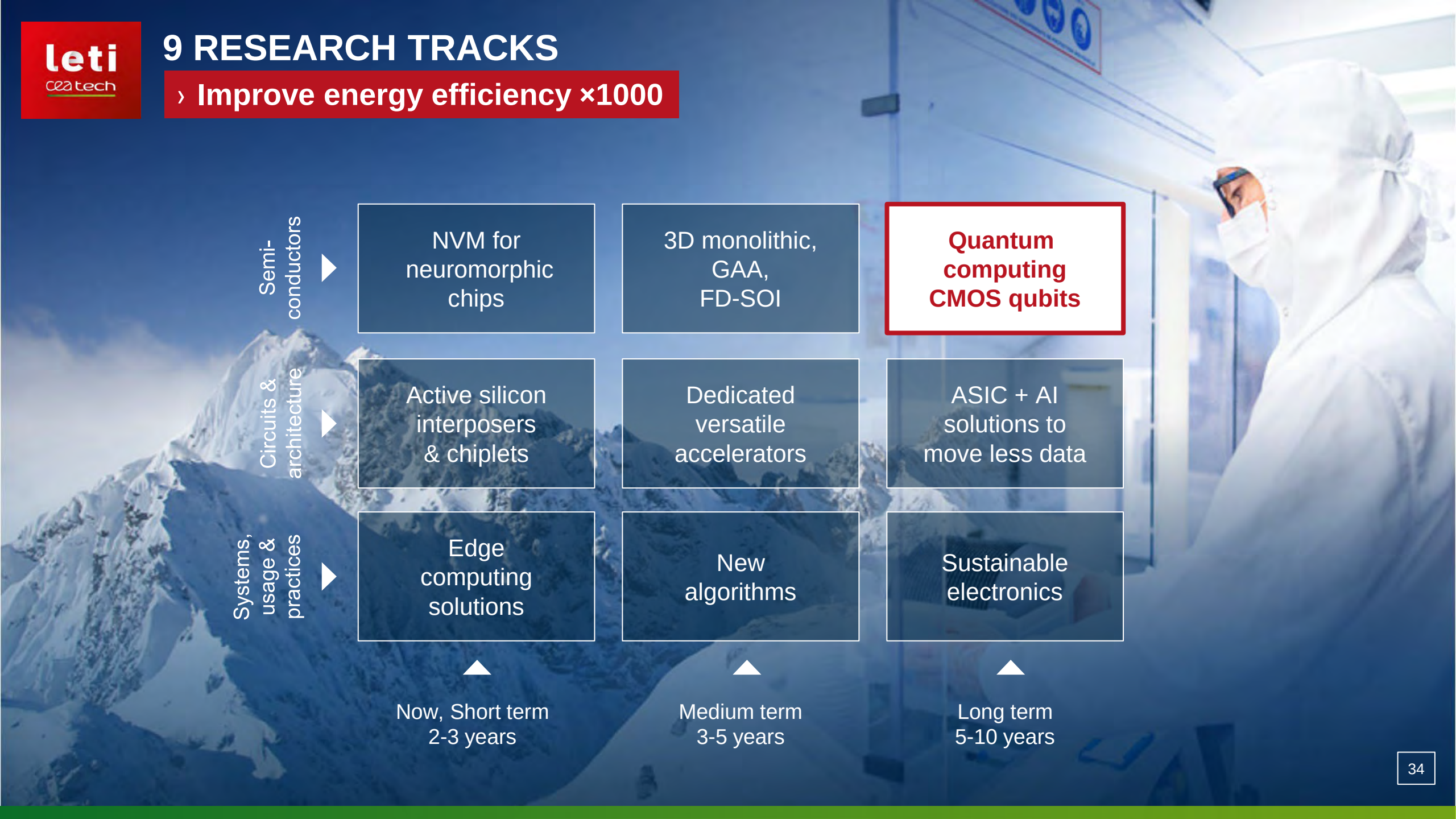


7 stacked nanosheets

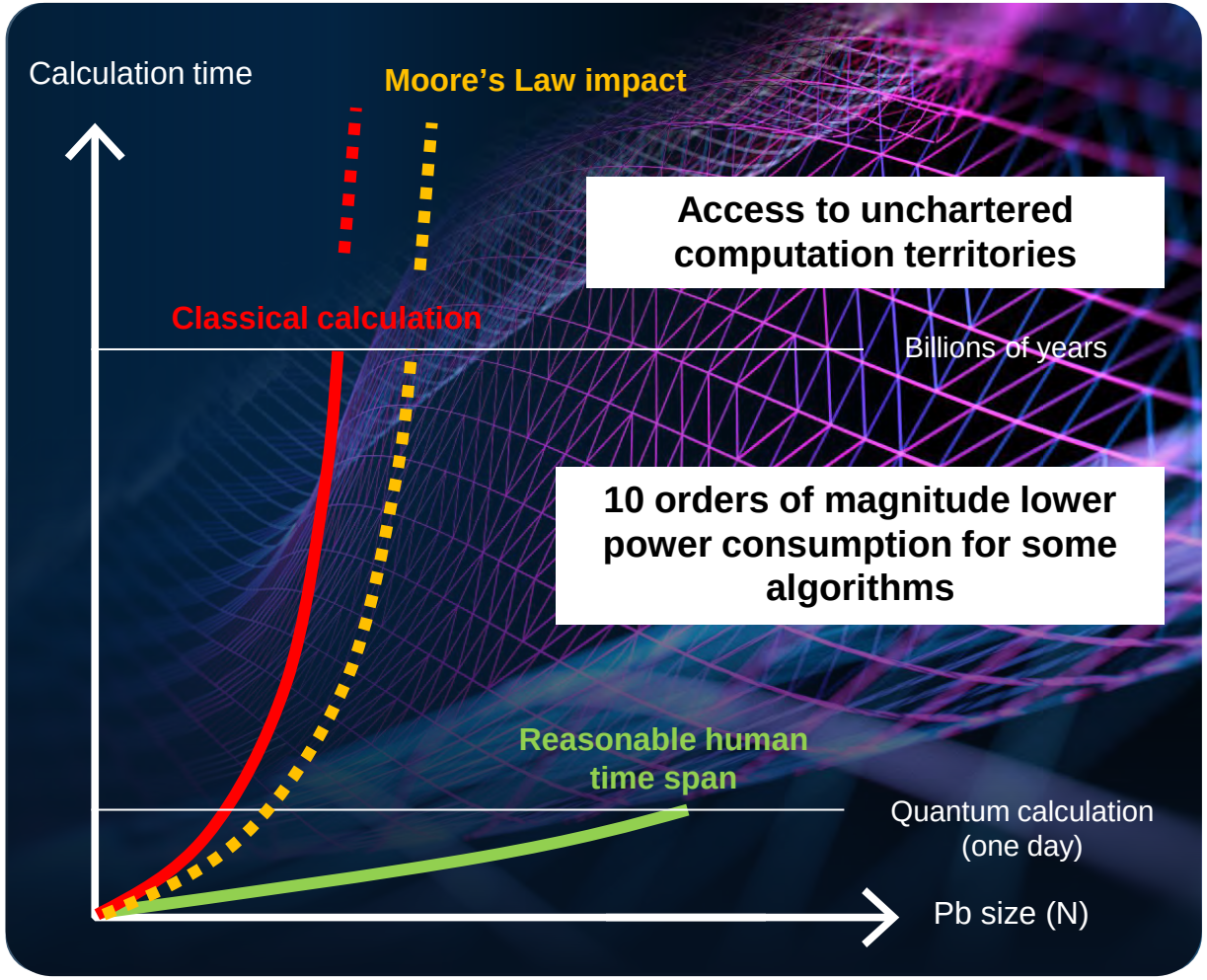
VLSI 2020

9 RESEARCH TRACKS

› Improve energy efficiency ×1000



QUANTUM COMPUTING PROMISES



Transport & logistics
- travel optimization
- fleet management

Healthcare
- molecular simulation
- drug discovery

Energy
- management and optimization of renewable energies

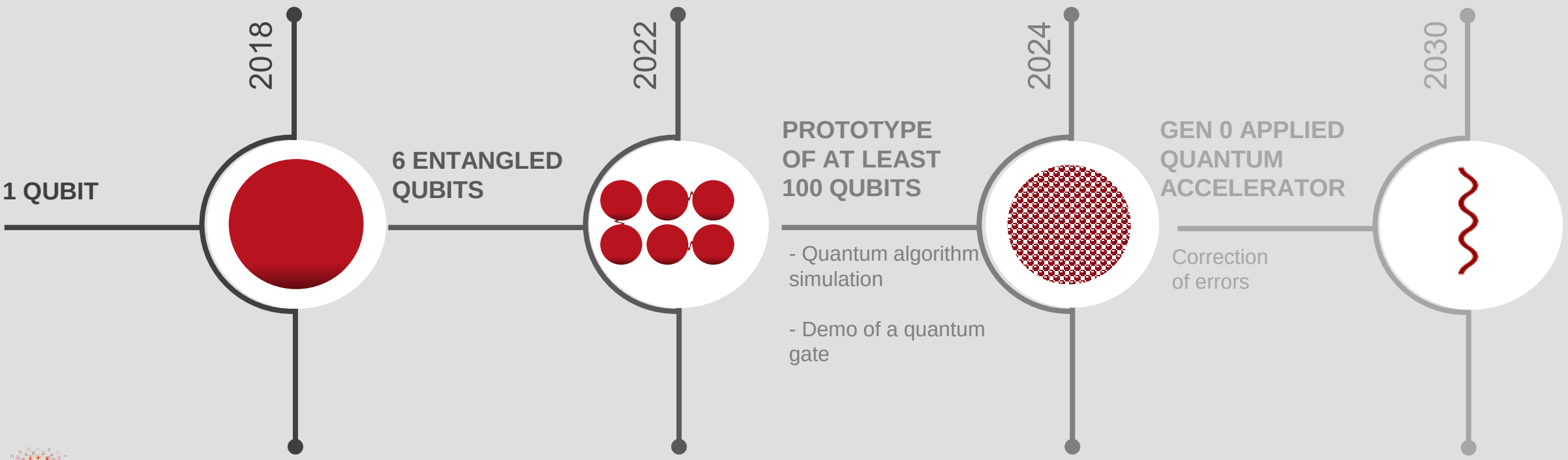
Manufacturing of **New materials**

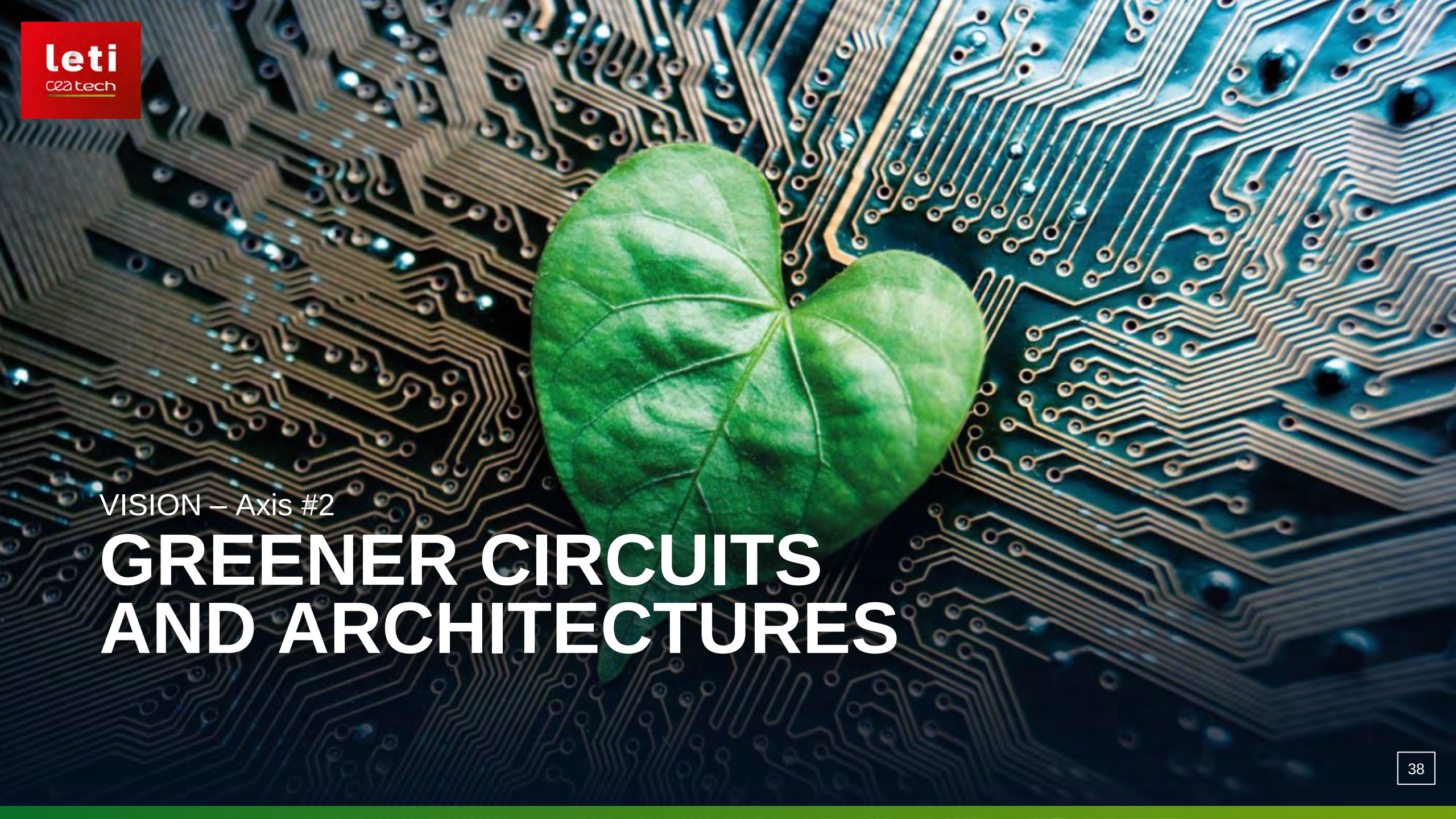
SEVERAL TECHNOLOGIES STILL IN COMPETITION

	PHOTON	ELECTRONS				ATOMS	
	Photons	Super-conducting	Silicon	NV Centers	Majorana Fermions	Cold Atoms	Trapped Oons
Qubit size	$(100\mu m)^2$	$(100\mu m)^2$	$(100nm)^2$			atomes	$(1mm)^2$
Two gate fidelity	98%	99,4%	99,6%	92%		98%	99,9%
Readout fidelity	50%	95%	99%	93%		99%	99,9%
Speed	1ms	250 ns	≈1µs				100µs
Temperature	4K/10K for photons generators and detectors	~15mK	1K	300K	15mK	15mK	10K
Entangled qubits	70 (China)	65 (IBM & Google)	3 (Rikken)	6		196 (Pasqal)	14 (AQT)
Scalability	100s	100s	millions	100s		100s	100

CEA-LETI'S QUANTUM ROADMAP

› Ambitious national research program launched by President Macron



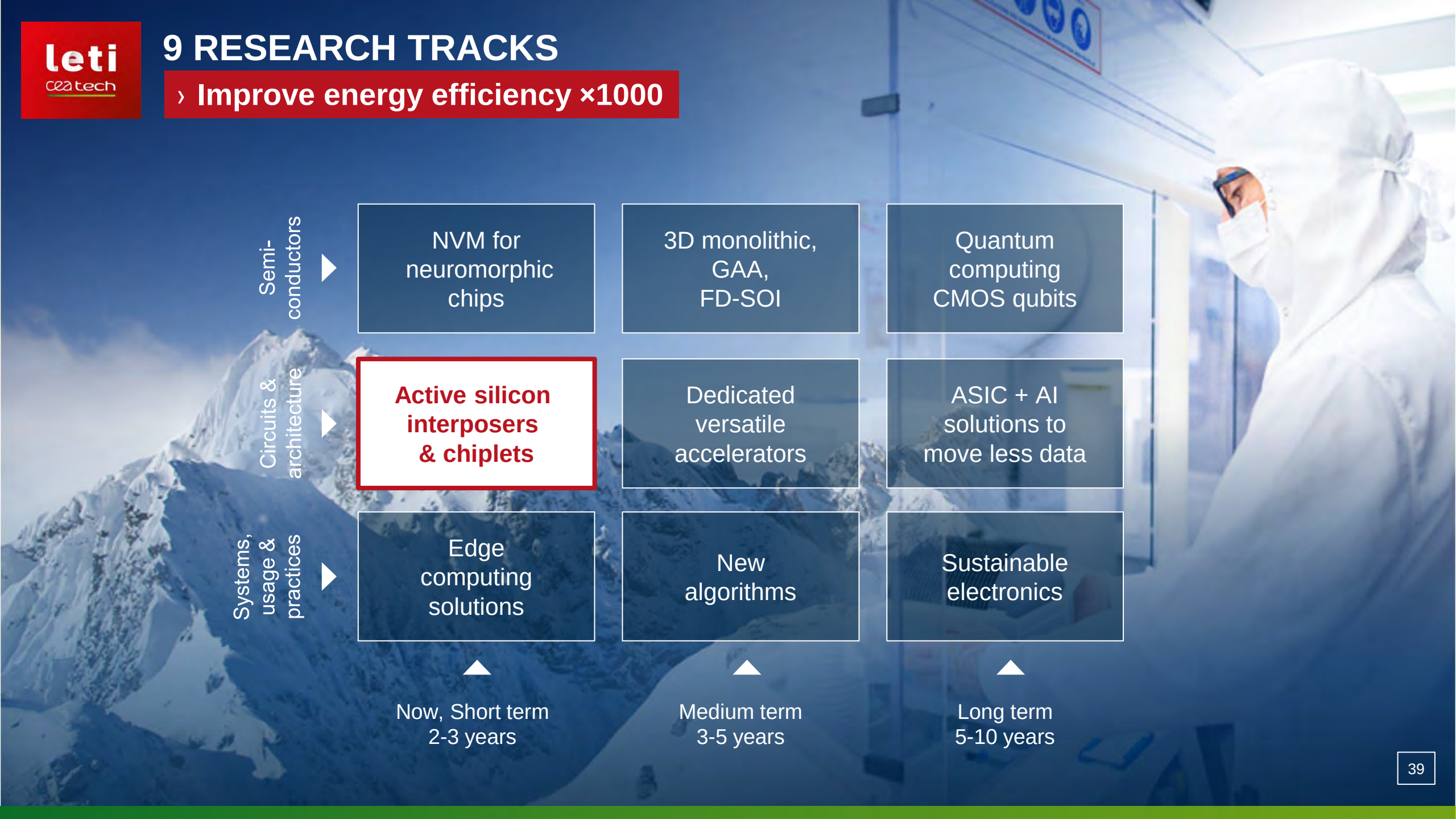


VISION – Axis #2

GREENER CIRCUITS AND ARCHITECTURES

9 RESEARCH TRACKS

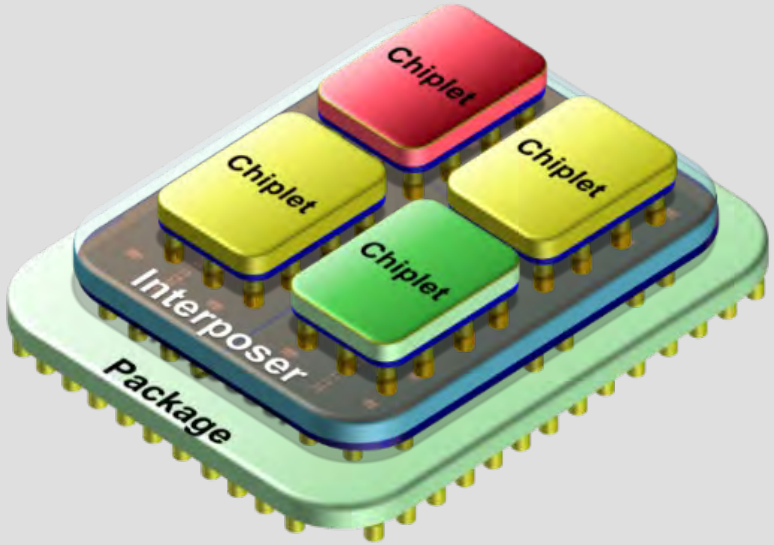
› Improve energy efficiency ×1000



ACTIVE SILICON INTERPOSERS & CHIPLETS

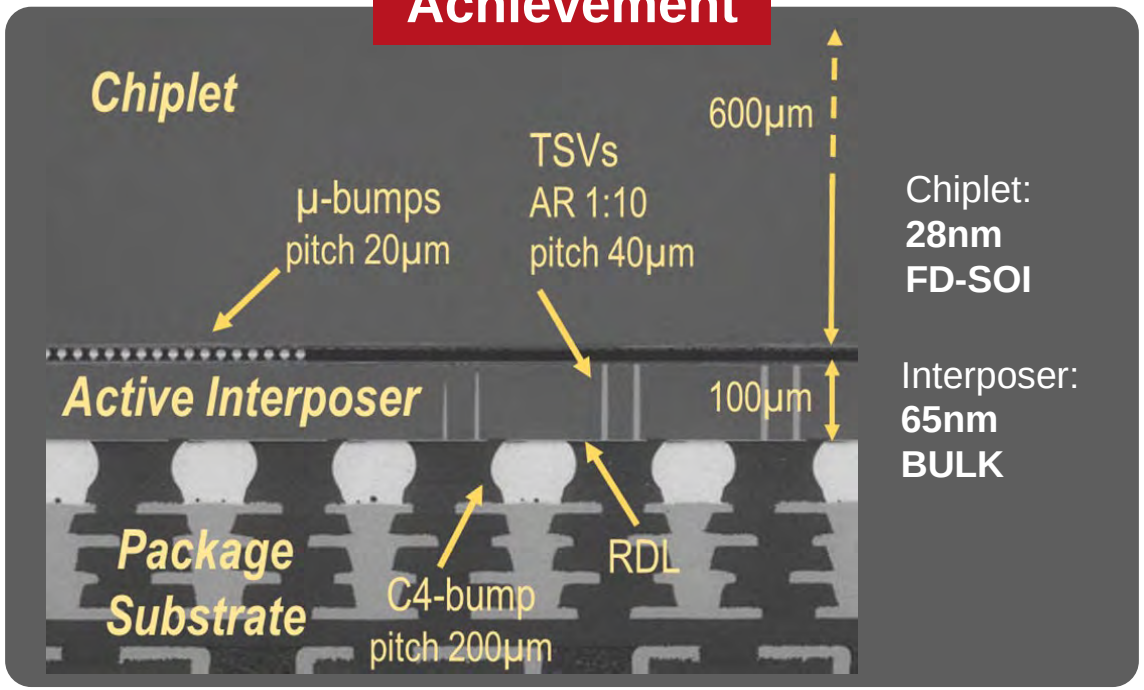
› Improve energy efficiency ×10+

Concept



Improve parallelism, power performance, versatility and cost with a modular architecture based on smaller chips

Achievement



The power of 10 laptops with a surface of only 200mm²

100GOPS, 10GOPS/Watt

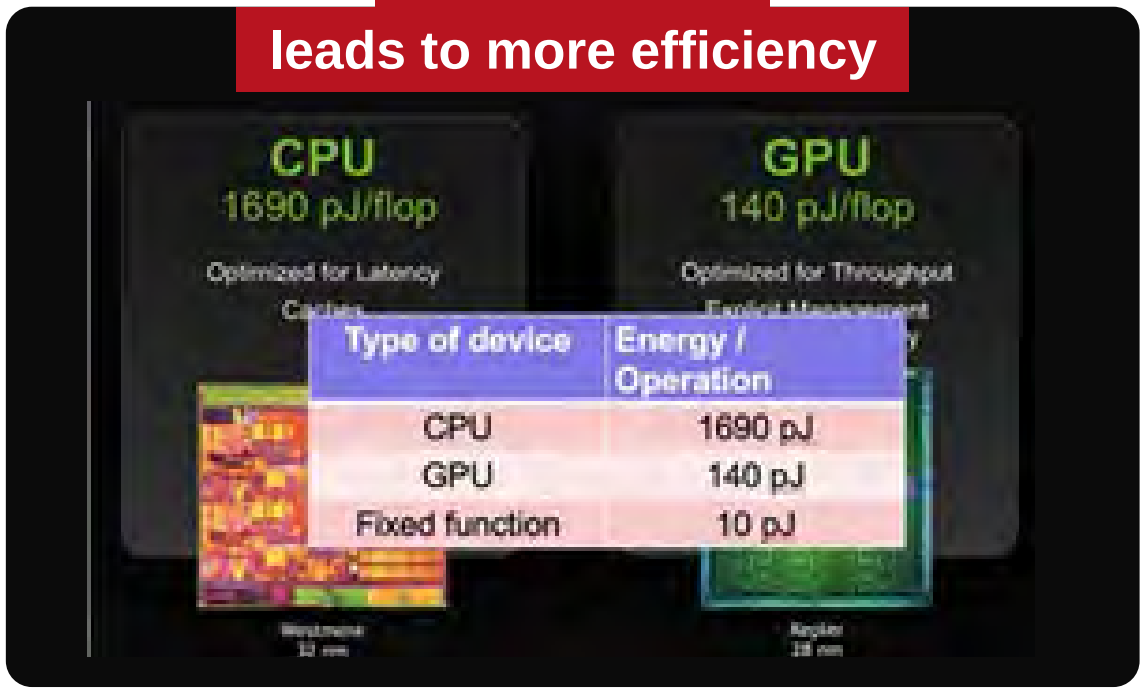
9 RESEARCH TRACKS

› Improve energy efficiency ×1000

DEDICATED VERSATILE ACCELERATORS

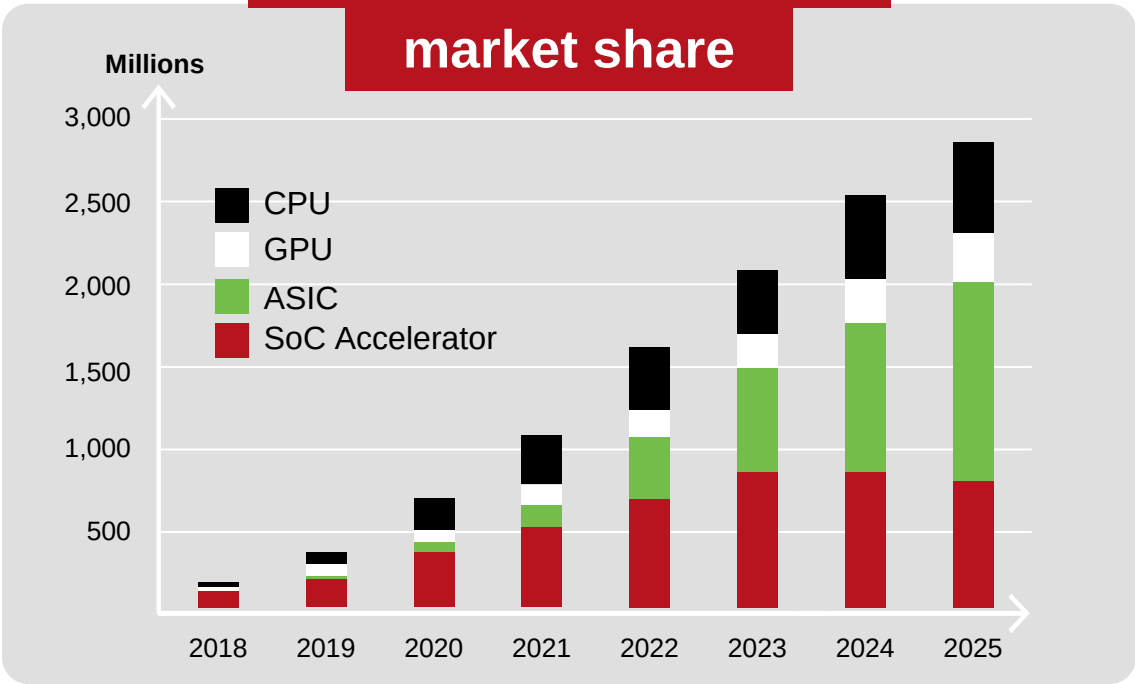
› Improve energy efficiency ×100+

Specialization leads to more efficiency



A gain in energy efficiency ×150 is possible

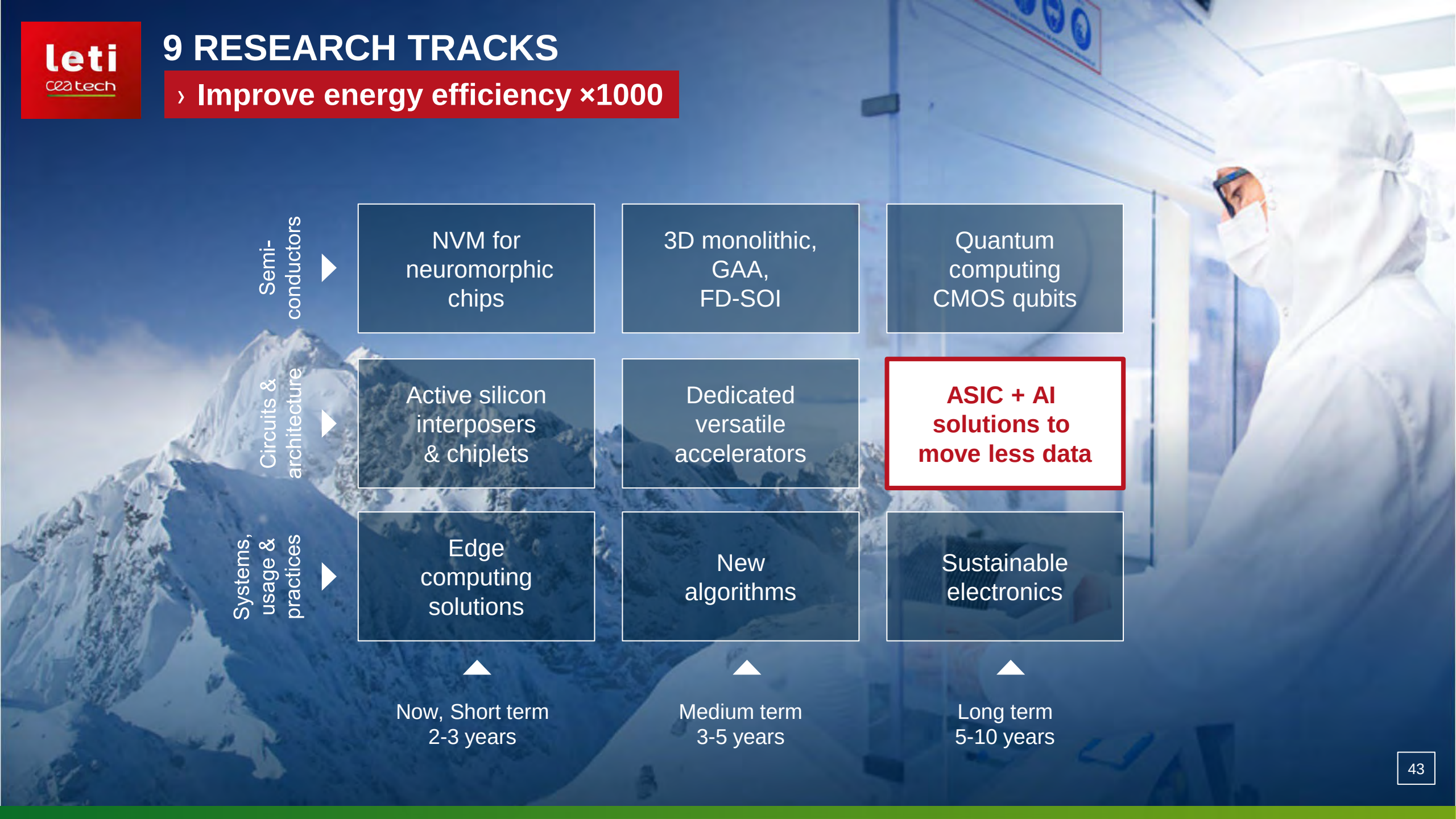
Deep learning chiplets' market share



By 2022, ASICs will take the lead

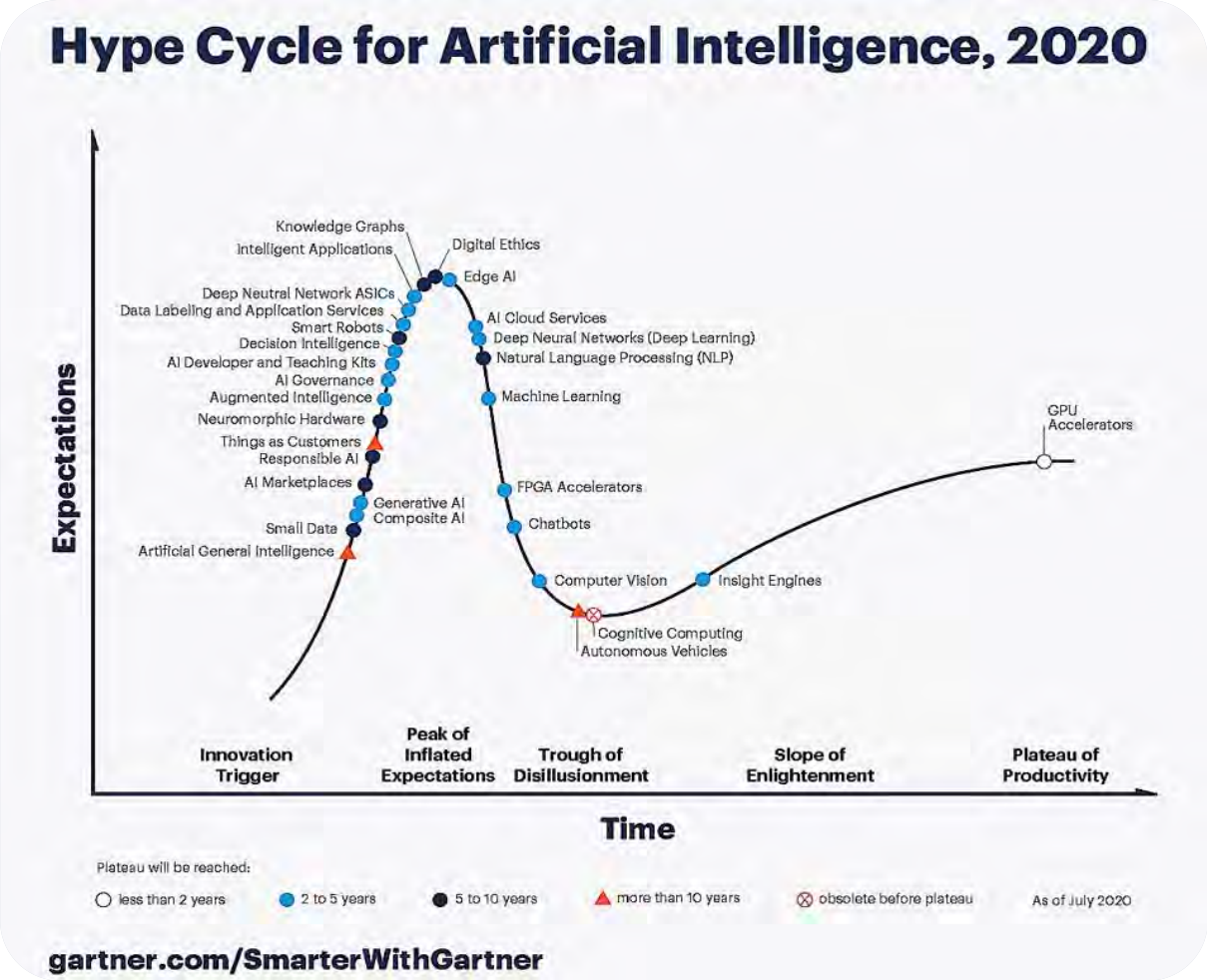
9 RESEARCH TRACKS

› Improve energy efficiency ×1000



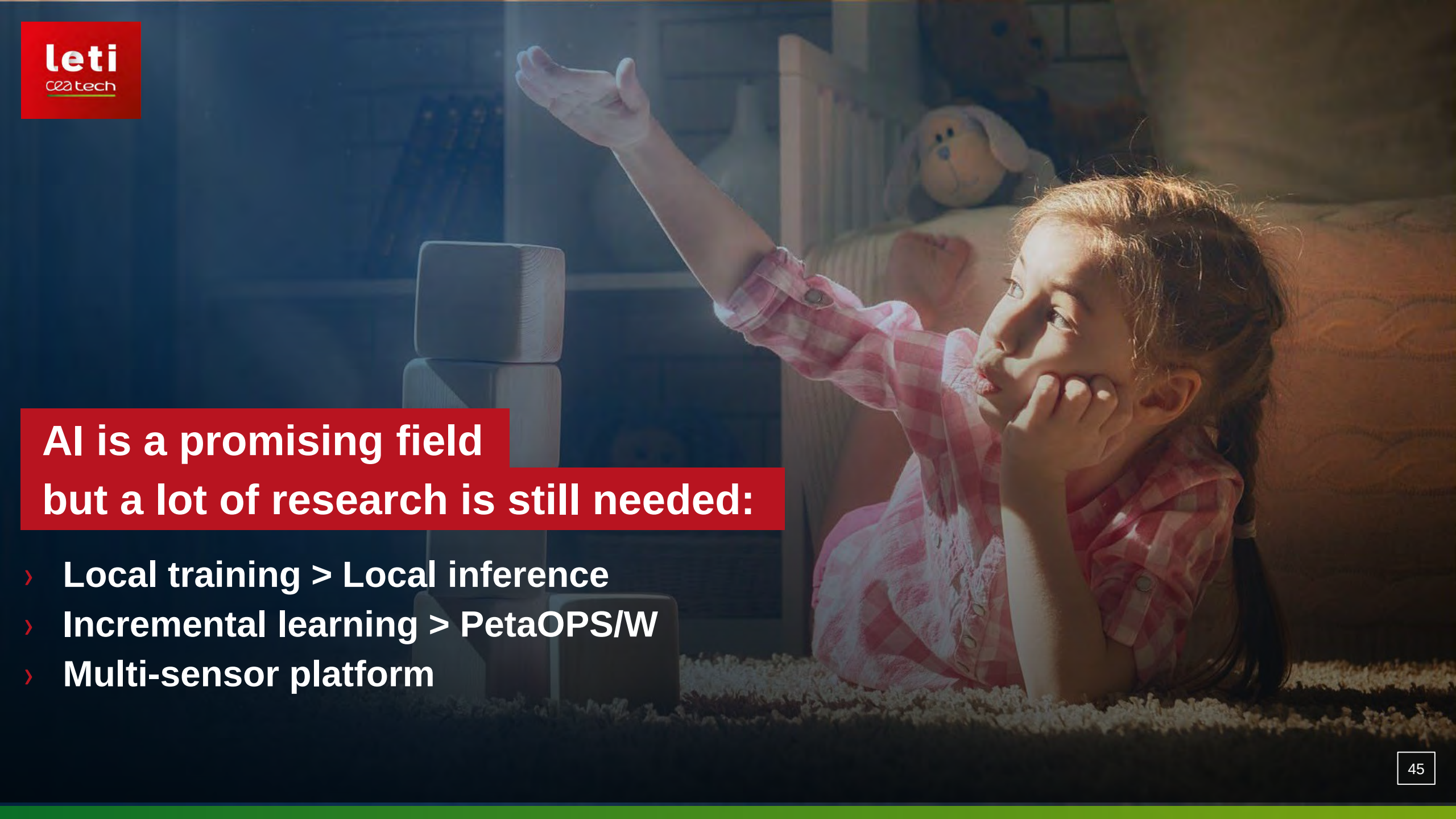
ARTIFICIAL INTELLIGENCE

› Past, present or future?



The future of AI: embedded learning & embedded inference

- R&D on AI:
  huge technological advances lie ahead
- Lots of room for innovation
  and value creation

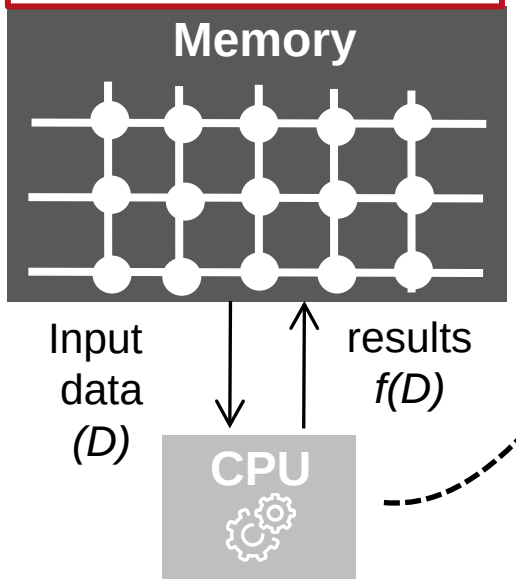


AI is a promising field but a lot of research is still needed:

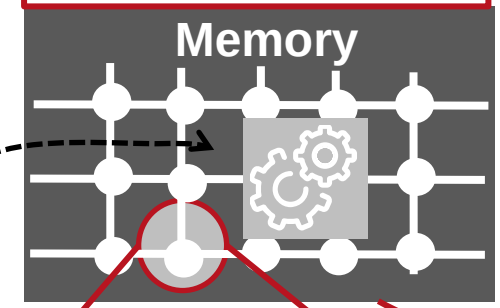
- Local training > Local inference
- Incremental learning > PetaOPS/W
- Multi-sensor platform

IN-MEMORY-COMPUTING

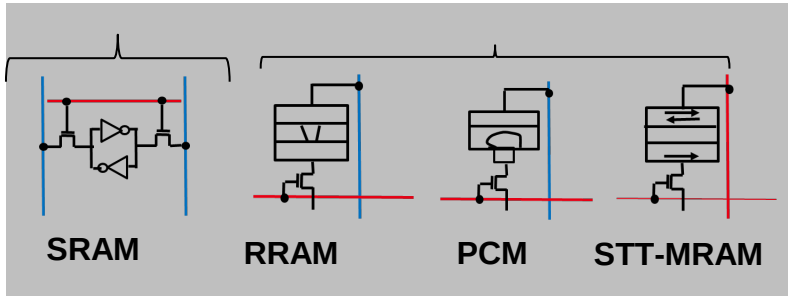
Von Neumann computing



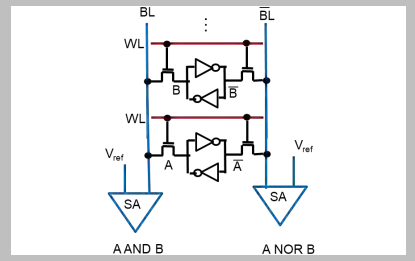
In-memory computing



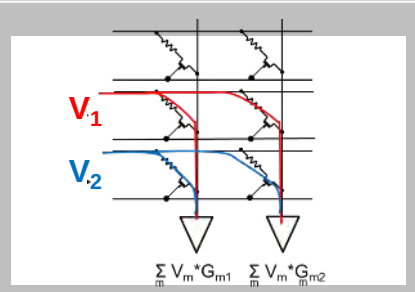
Memory technologies



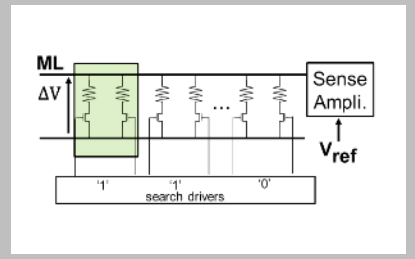
Logic and arithmetic operations



Digital operations using SRAM



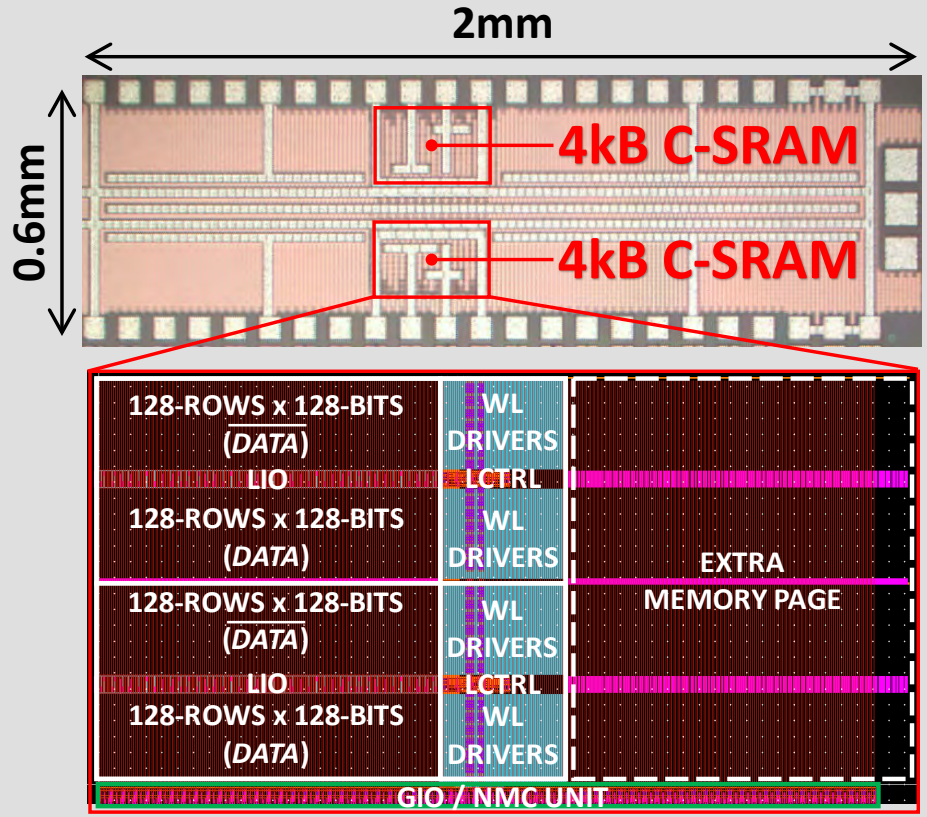
Analog: multiply and accumulate



Searching / matching (CAM)

CEA-LETI'S IN-MEMORY-COMPUTING

› Improve energy efficiency ×100+



Logic & **Arithmetic**

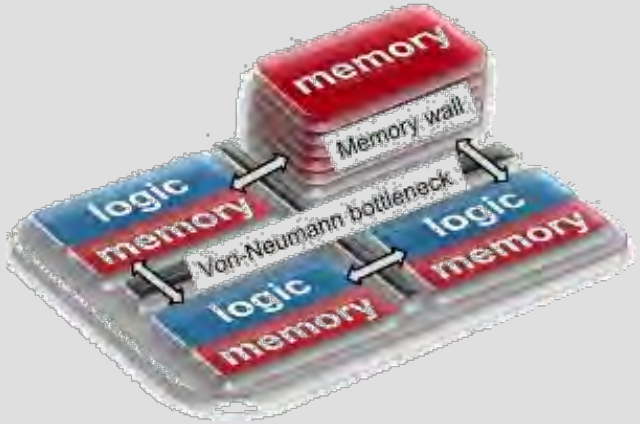
(AND, OR, XOR) *(ADD, MUL, MAC)*

Energy efficient vector-processing unit

- Multiple row activation to increase parallelism
- 22 nm FD-SOI process technology
- 83TOPS/W/mm²

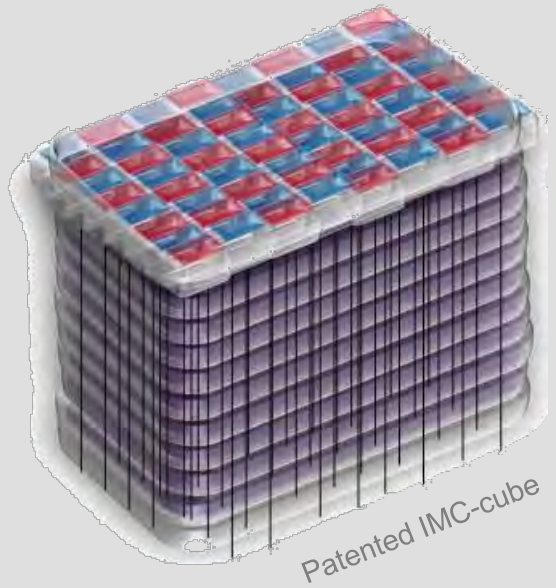
MYCUBE, TOWARDS THE ULTIMATE IN-MEMORY-COMPUTING

Today



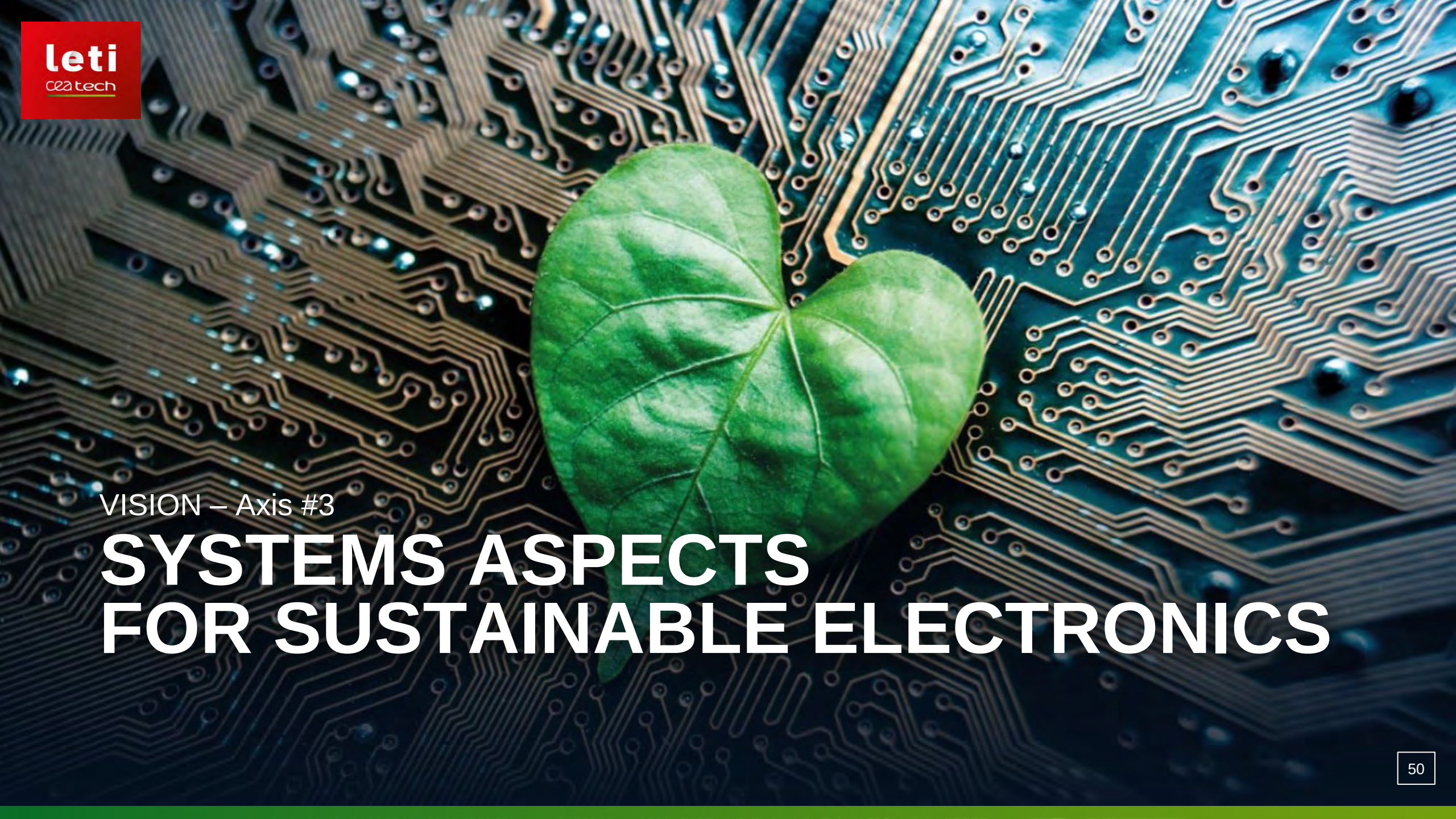
Problem:
Energy-efficiency in data-abundant integrated circuits

Tomorrow



- vertical memories
- 3D stacks
- vertically stacked nanowires
- circuit demonstrators
- software tools

Solution:
Highly-parallel In-Memory-Computing

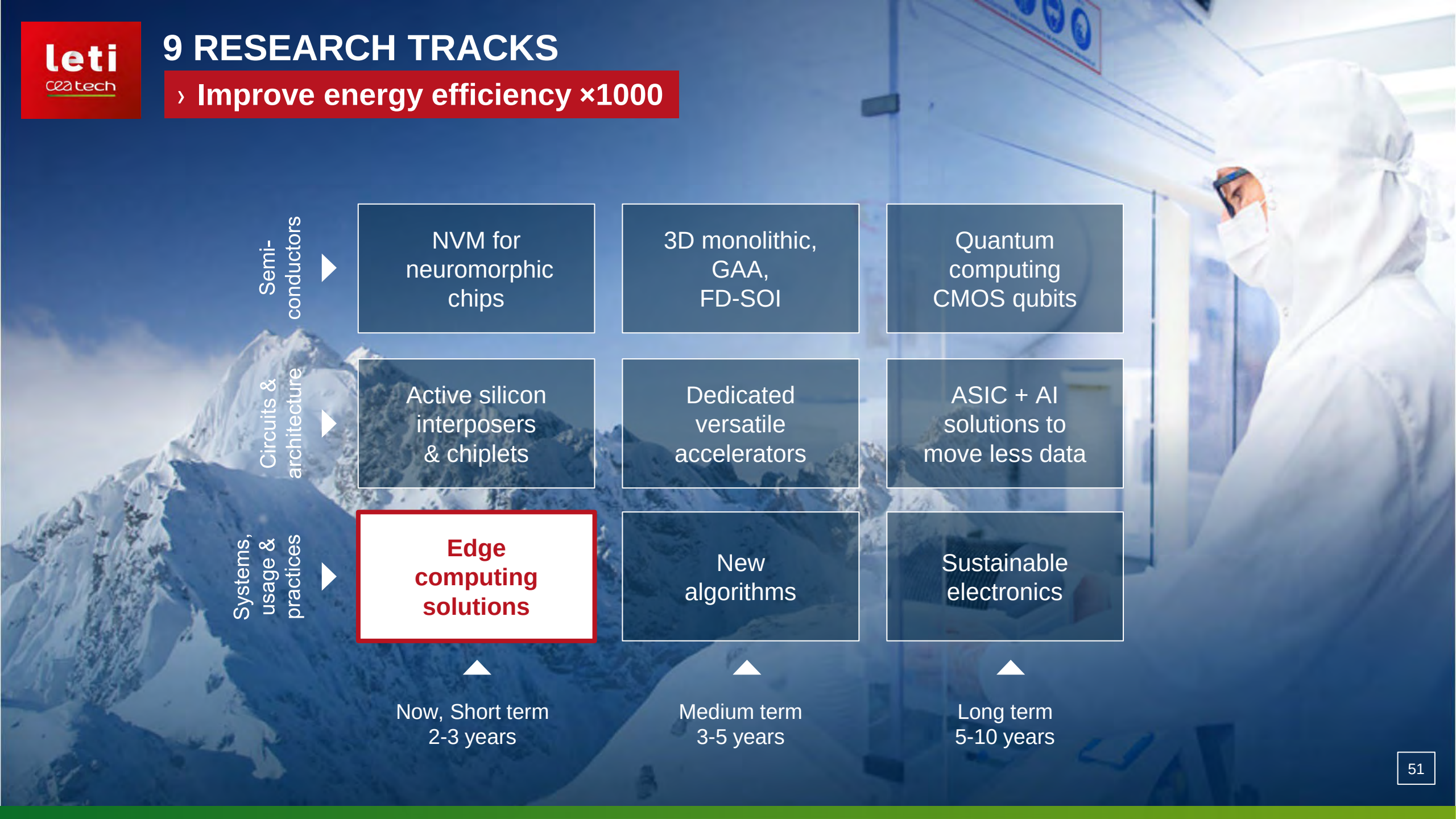


VISION – Axis #3

SYSTEMS ASPECTS FOR SUSTAINABLE ELECTRONICS

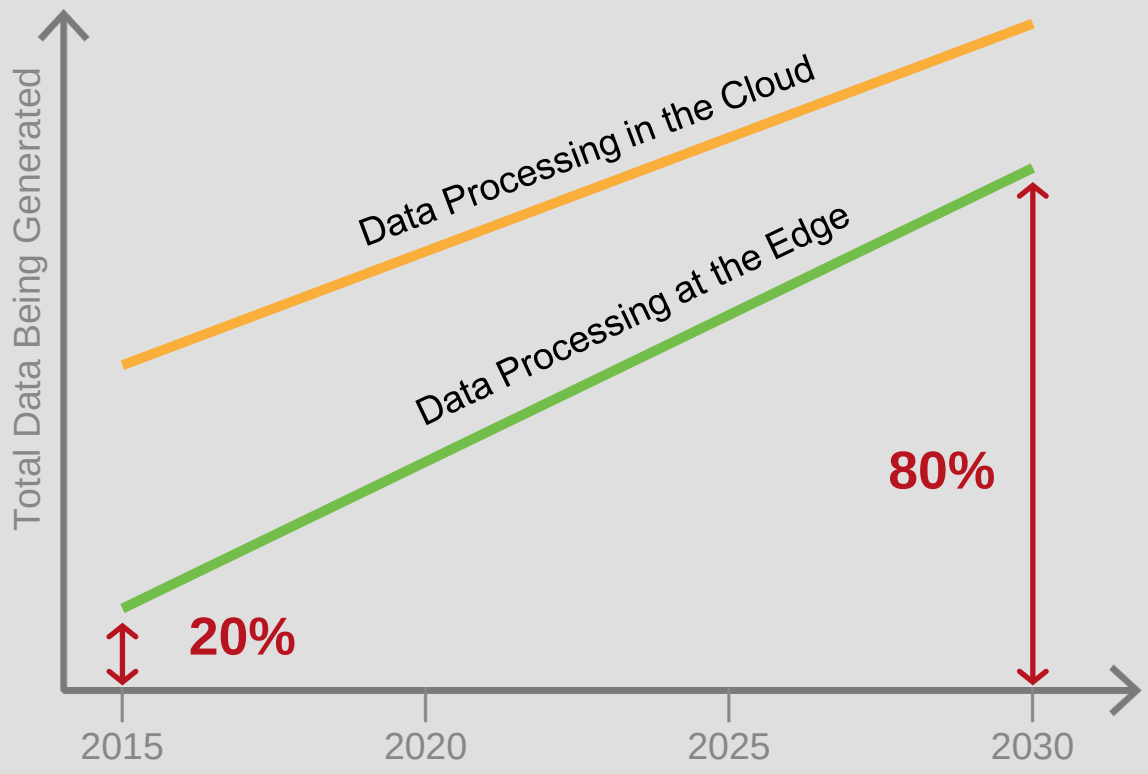
9 RESEARCH TRACKS

› Improve energy efficiency ×1000



EDGE-COMPUTING SOLUTIONS

› Improve energy efficiency ×10⁶



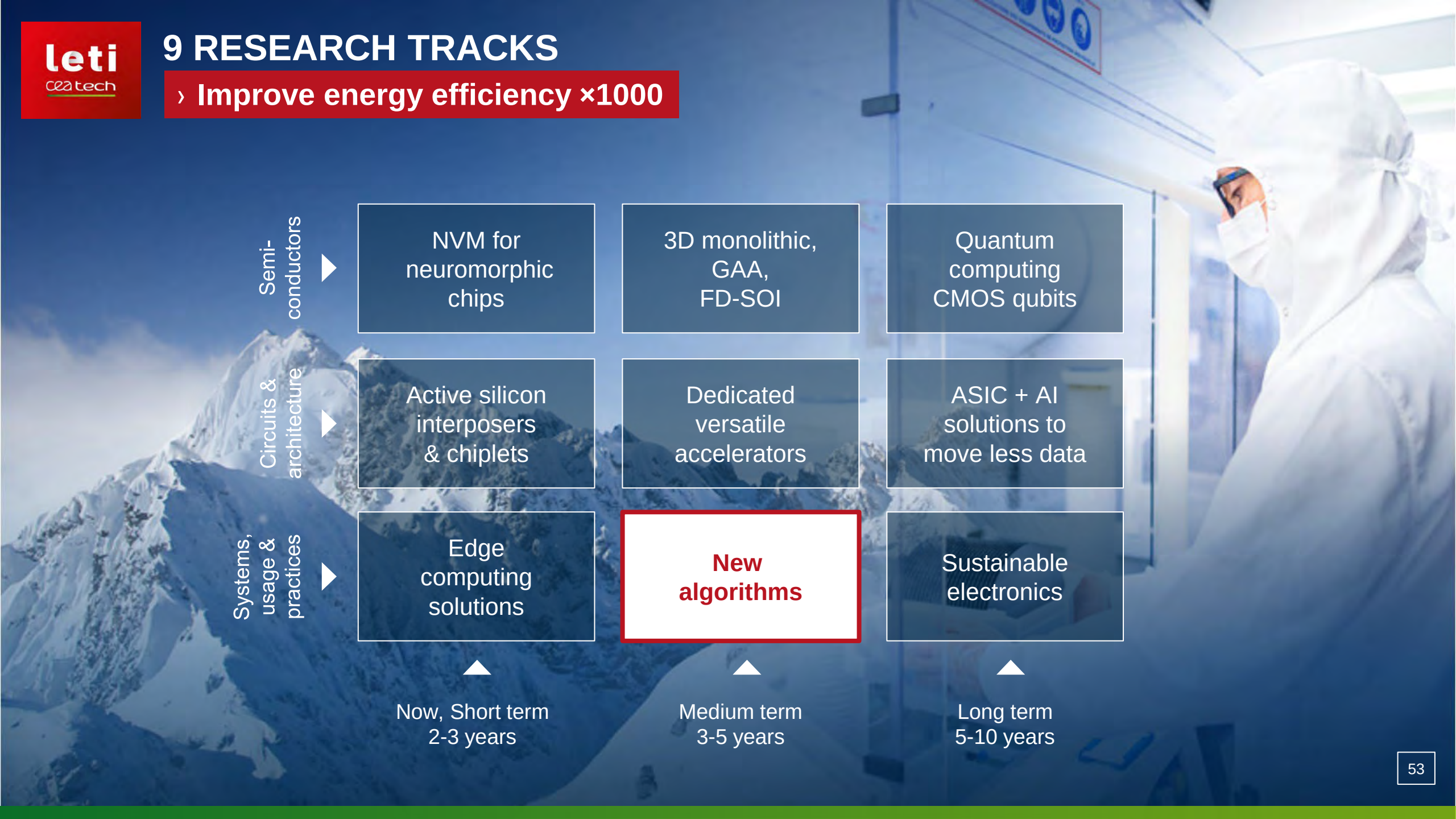
Source: International Business Strategies, Inc. (IBS) – sept 2020

Reduce the overall energy requirements and improve service quality

› Transferring/storing 1 GB of data through the Internet uses ~5kWh, instead of 5×10^{-6} kWh if done locally

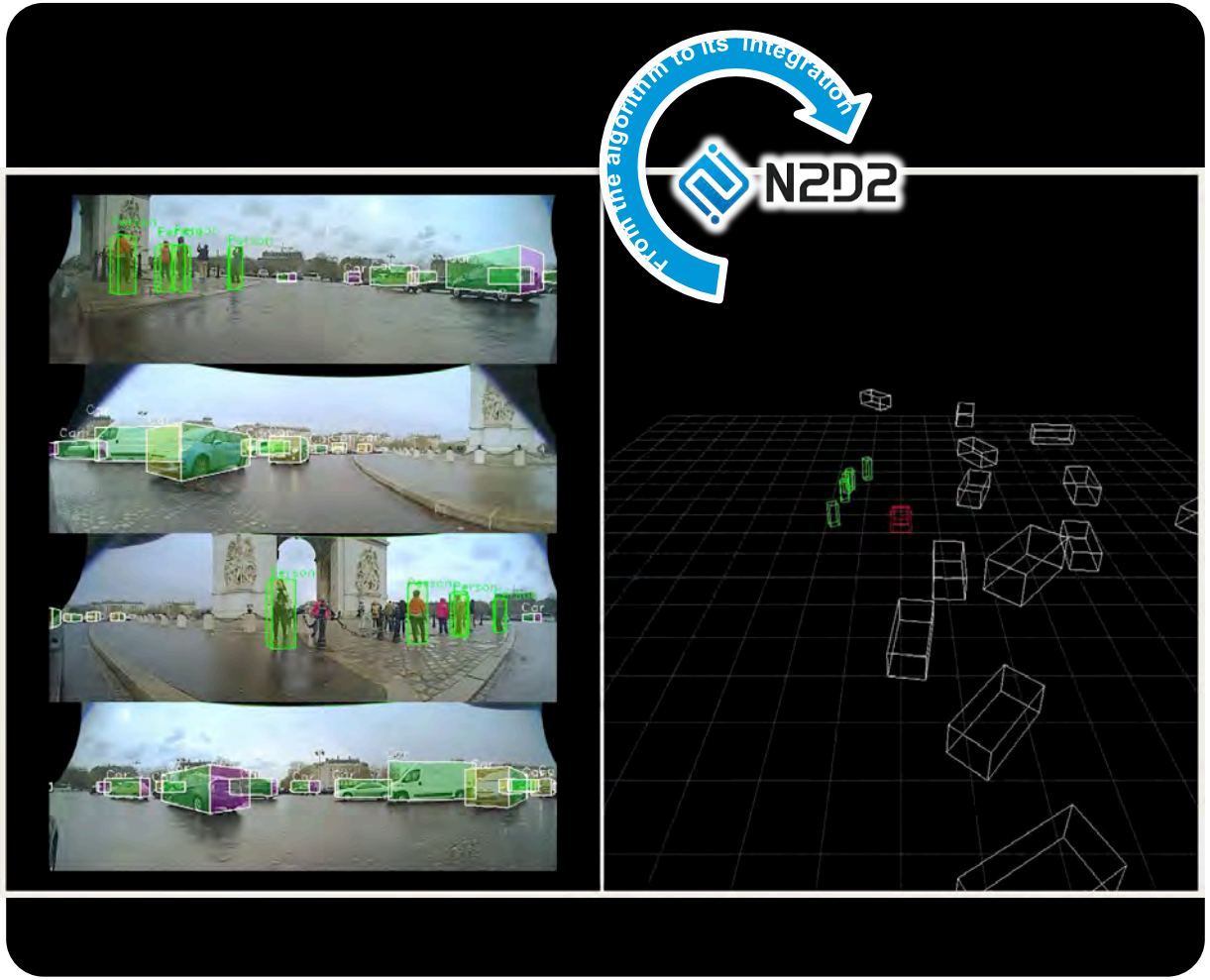
9 RESEARCH TRACKS

› Improve energy efficiency ×1000



DEEP LEARNING PLATFORM FOR EMBEDDED AI

› Improve energy efficiency ×10+



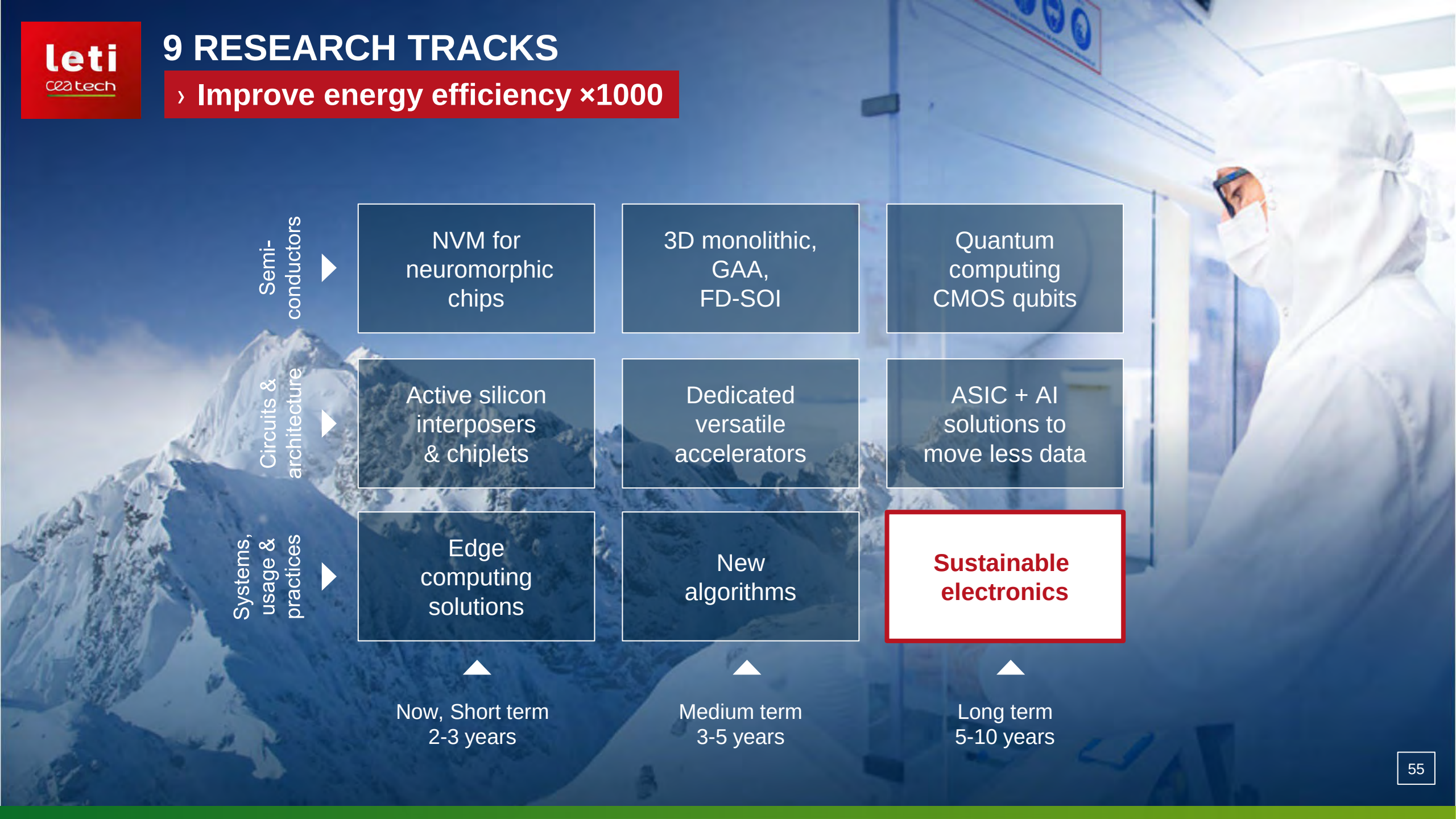
N2D2: software tool to explore DNN with hardware constraints

- computing power
- memory
- data accuracy
- power consumption

…and develop energy-optimized perception algorithms for ADAS

9 RESEARCH TRACKS

› Improve energy efficiency ×1000



TOWARDS SUSTAINABLE ELECTRONICS

Production

› reduction of waste and water
› recycling
› reduction of critical materials

IC design

› new computing paradigms
› stronger ultra low-power expertise

Eco-design of products

› extended lifetime
› life cycle analysis

End of life management

› recycling more materials from electronic waste

OUTLOOK

IMPLICATIONS FOR THE SEMICONDUCTOR RESEARCH AGENDA

NEW PARADIGM IS NEEDED TO FAVOR SOBRIETY/FRUGALITY VS. DECLINISM

TRENDS

We need to drastically reduce the energy and environmental footprint of electronic devices

Declinism
pessimist's approach
Reducing or limiting performance

Sobriety
athlete's approach
Maximize performance for a given resource

The Challenge: Capitalize on hardware and software advances to master global digitization and preserve the planet

If you share the same vision, Join us!

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