



**How to foster innovation  
*the past and the future ?***



***the future***

The background of the slide is a close-up photograph of several bright green leaves. The leaves are in sharp focus in the foreground, showing their veins, and become increasingly blurred as they recede into the background, creating a sense of depth. The overall color palette is a range of greens, from light lime to deep forest green.

# **Green electronics:** ***a technology for a sustainable future***

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project  
vision success development  
management ideas  
teamwork  
STRATEGY  
invent  
team  
motivation  
leadership  
planning  
innovation  
action

## Green Materials:

Abundant (non toxic)  
materials

## Green Technologies:

Simple and low energy  
processes

The background of the image consists of several green leaves on a branch, set against a blurred green background. The leaves are in various shades of green, from light to dark, and their veins are clearly visible. The overall composition is clean and natural.

**Alternative  
electronics is needed  
because ...**

**What we are generating?**



**HIGH-TECH TRASH**

**This is recycling?**





**This is waste selection?**



**Can we change this?**



# International e-waste shipments

Export of e-waste



Source: Greenpeace, Basel Action Network



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CENTRO DE INVESTIGAÇÃO DE MATERIAIS

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INSTITUTO DE INVESTIGAÇÃO EM  
NANOTECNOLOGIA E  
MATERIAIS

**Is this the future?**



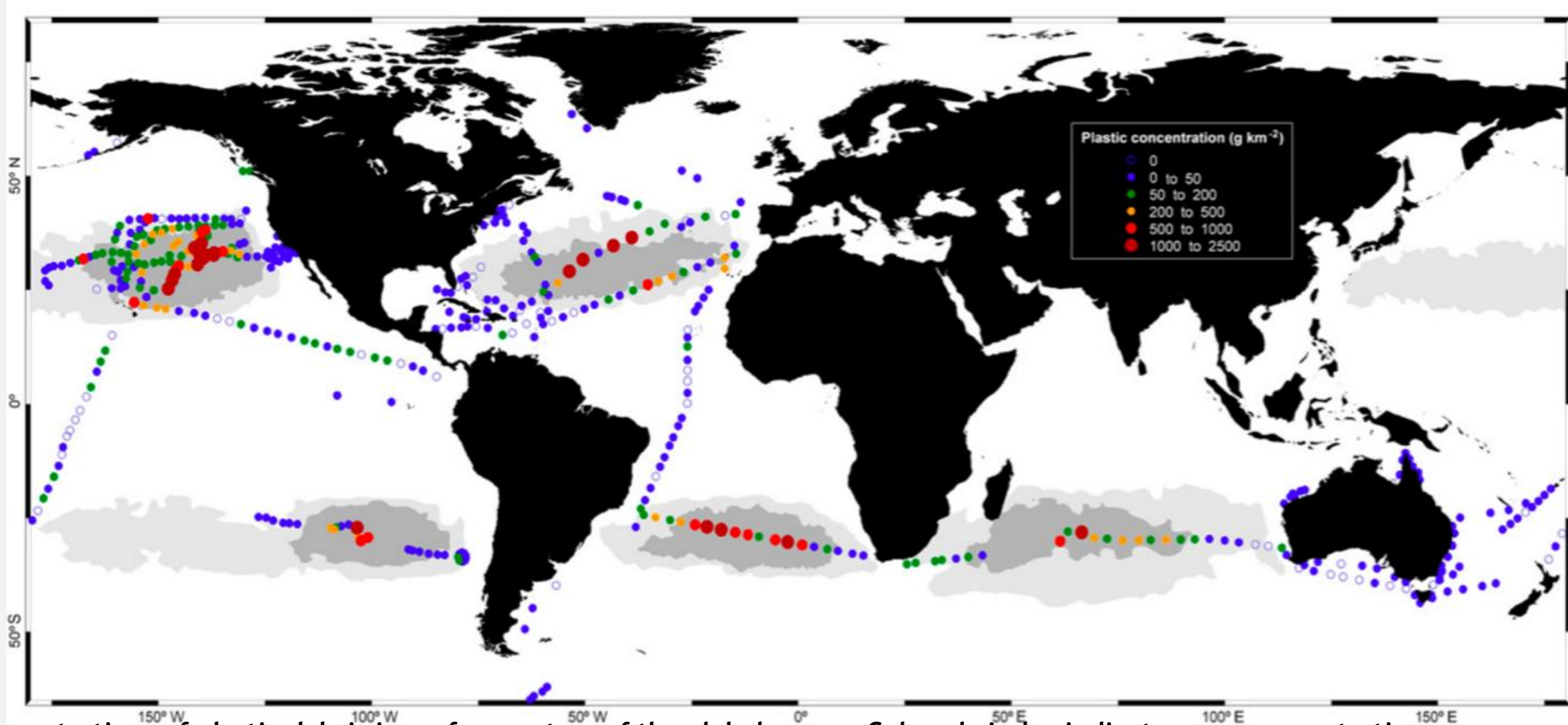
# 5 countries dump more plastic into the oceans than the rest of the world



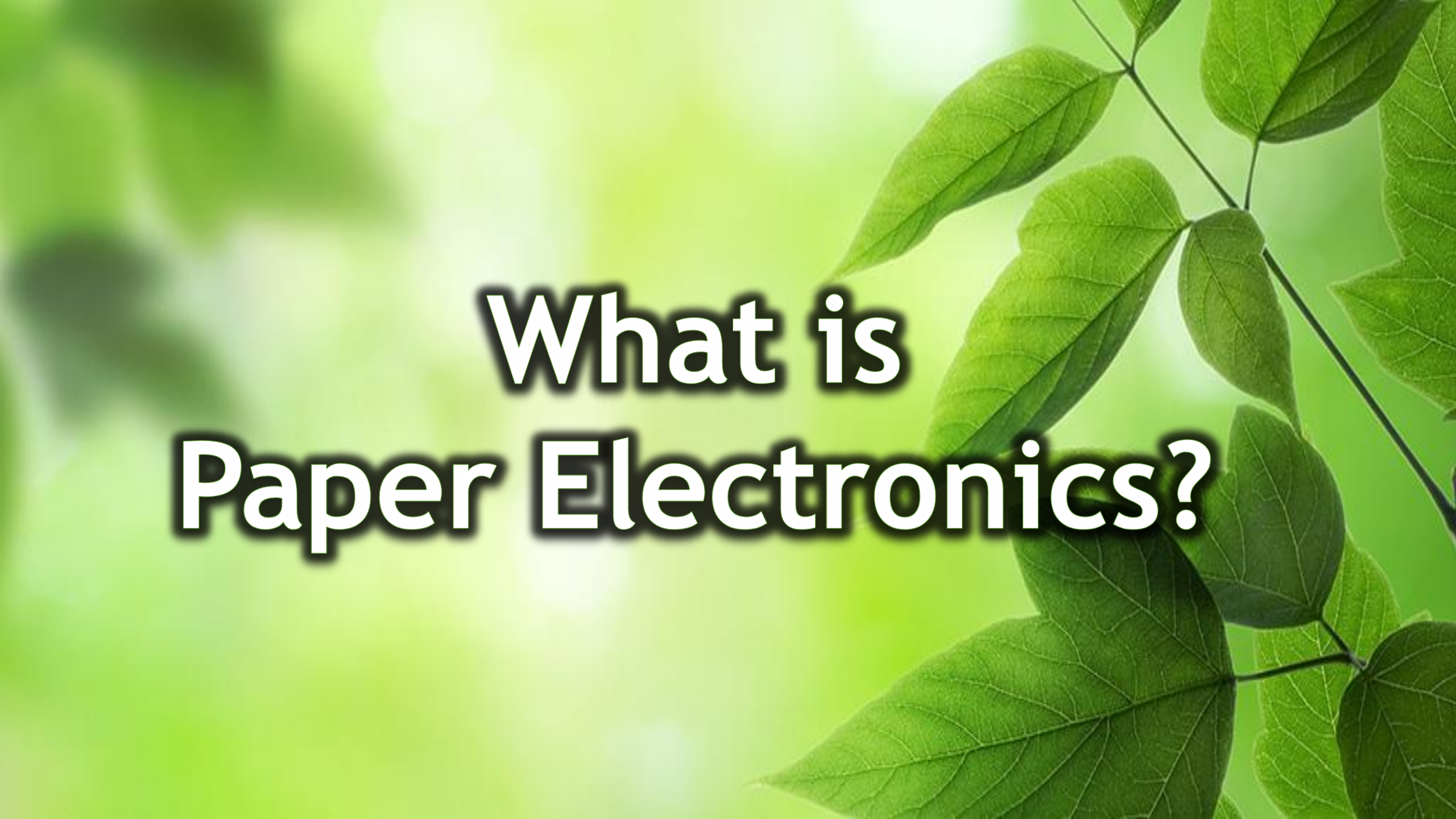
At this rate, we would expect nearly one ton of plastic for every three tons of fish in our oceans by 2025 – an unthinkable number with drastic economic and environmental consequences.

# We dump 8 million tons of plastic into the ocean each year. Where does it all go?

## Every ocean now has a massive plastic garbage patch



Concentrations of plastic debris in surface waters of the global ocean. Colored circles indicate mass concentrations

The background of the image consists of several bright green leaves, likely from a maple tree, with detailed vein patterns. The leaves are set against a soft, out-of-focus background of more green foliage, creating a natural and fresh aesthetic. The lighting is bright, highlighting the texture and color of the leaves.

# **What is Paper Electronics?**

Sometimes we are inspired by science fiction ...





# Why paper?

Cellulose is nature's most common building block.

In a **bio-economy** and **circular-economy** in which **renewable materials** are one of the keys to a more sustainable future, **cellulose** has an active and a crucial role.

**and ...**



# ... cellulose is:

**Most abundant biopolymer environmentally friendly**

**Flexible and unbreakable**

**Low cost material**

**The lightest known material**

**Well established production technology (100 km/h)**

**Good dielectric properties**

**Paper is ubiquitous**

**Recyclable**



2-3 days

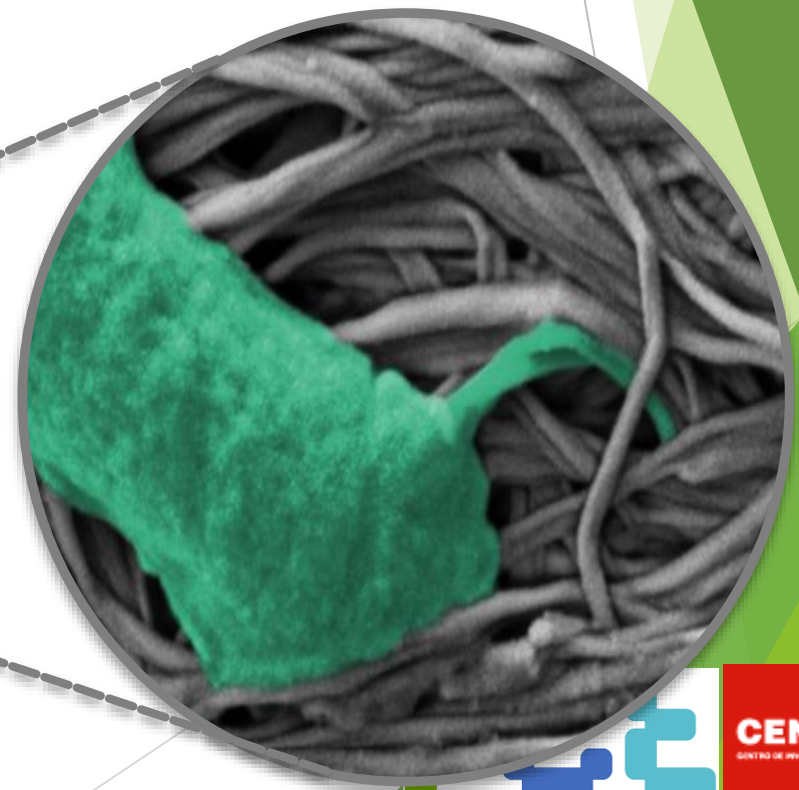
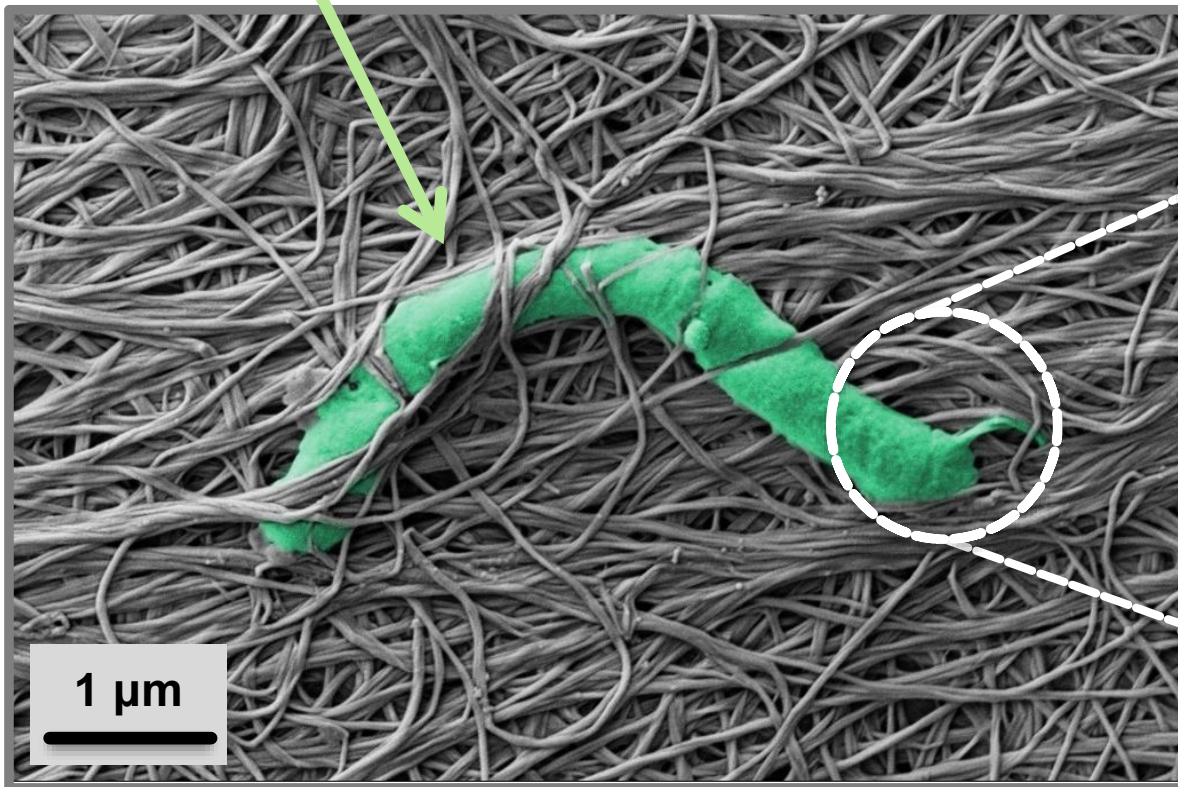
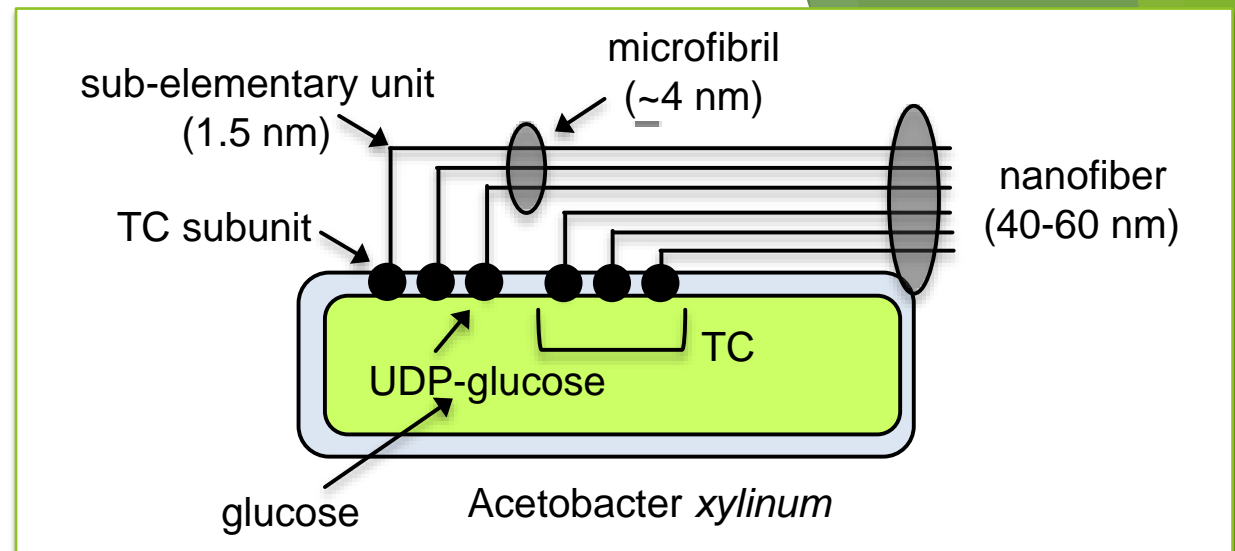


4-5 years

# Bacterial cellulose

► Produced by bacteria

Ex: *Acetobacter xylinum*



# Bacterial cellulose



Work done @CENIMAT

# Electronic devices

# Thin Film Transistors - *interstrate* structure

In 2008 ...

# e-Paper

# Paper-e®



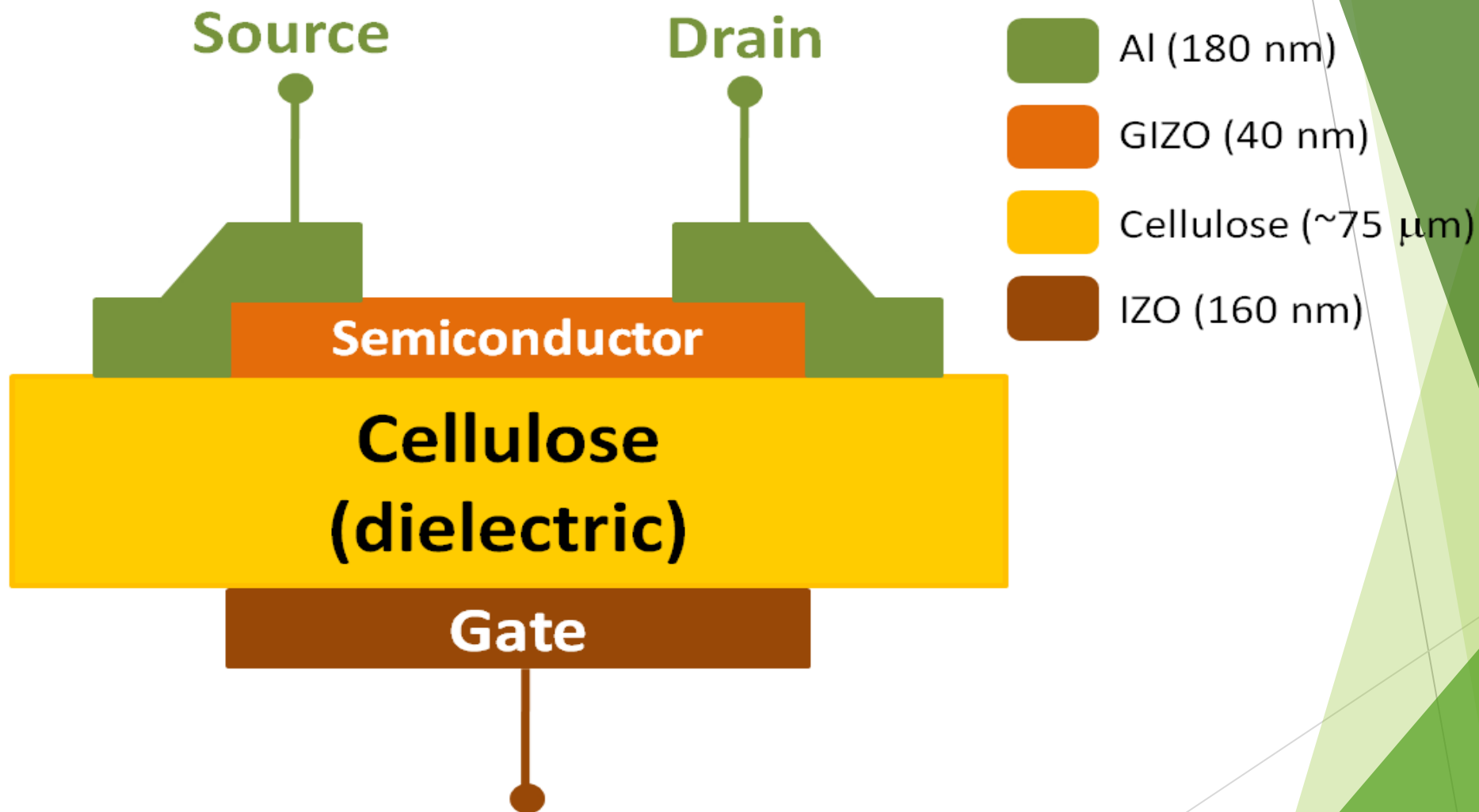
## Paper - e

Green electronics for the future



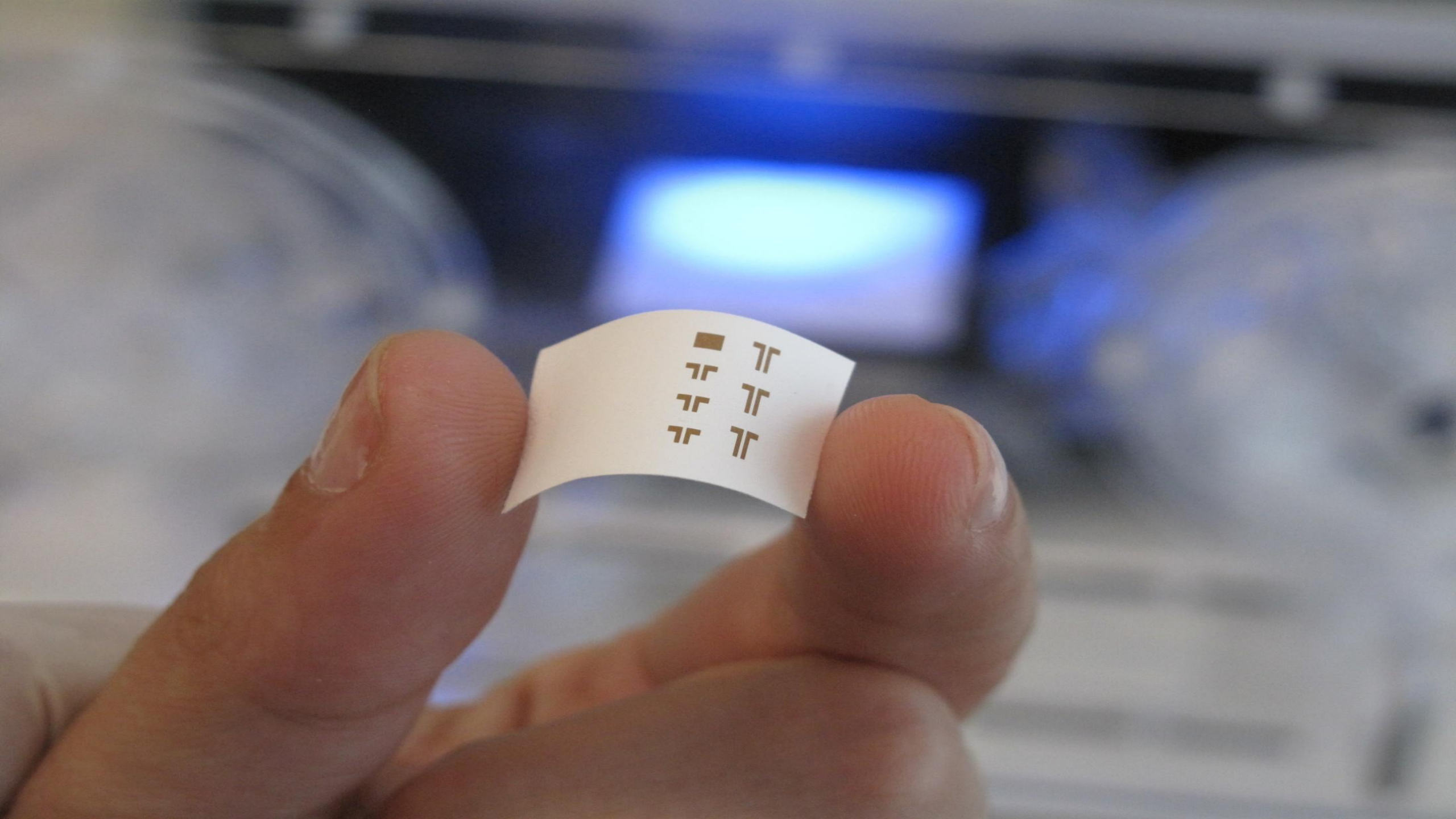
# Physical support AND Active function

# 1<sup>st</sup> Paper transistor (office paper)

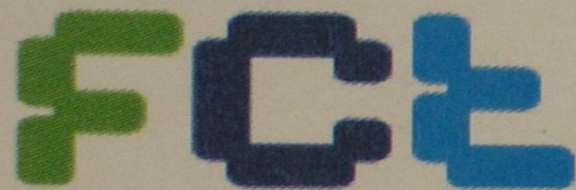


Fortunato, E. et al., High-Performance Flexible Hybrid Field-Effect Transistors Based on Cellulose Fiber Paper. *IEEE Electron Device Letters* 2008, 29, 988-990.

Patent: E. FORTUNATO, R. MARTINS, P. BARQUINHA, G. GONLAVES, N. CORREIA, PROCEDURE FOR THE USE OF NATURAL CELLULOSE MATERIAL, SYNTHETIC MATERIAL OR MIXED NATURAL AND SYNTHETIC MATERIAL SIMULTANEOUSLY AS PHYSICAL AND DIELECTRIC SUPPORT IN SELF-SUSTAINABLE FIELD EFFECT ELECTRONIC AND OPTOELECTRONIC DEVICES; PTI 40053-09-PT.



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FACULDADE DE  
CIÊNCIAS E TECNOLOGIA  
UNIVERSIDADE NOVA DE LISBOA

**CENIMAT I3N**





A3PLE DEMO1-V3.1C

A3PLE DEMO1-V3.1A

A3PLE

R2=200kohm

R2=200kohm R1=100kohm

Dangerous Gas detected

SOFT BATTERY  
1100mAh

A3PLE  
DEMO1-1/2



# TETRA solar

A. Vicente, H. Águas, T. Mateus, A. Araújo, A. Lyubchyk, S. Siitonen, E. Fortunato, R. Martins, Solar Cells for Self-Sustainable intelligent Packaging, *J. Materials Chemistry A*, 2015, DOI 10.1039/C5TA01752A.

Work done @CENIMAT

# Biosensors

# World Health Organization

**A**ffordable

**S**ensitive

**S**pecific

**U**ser-friendly

**R**apid and Robust

**E**quipment-free

**D**elivered to those in need

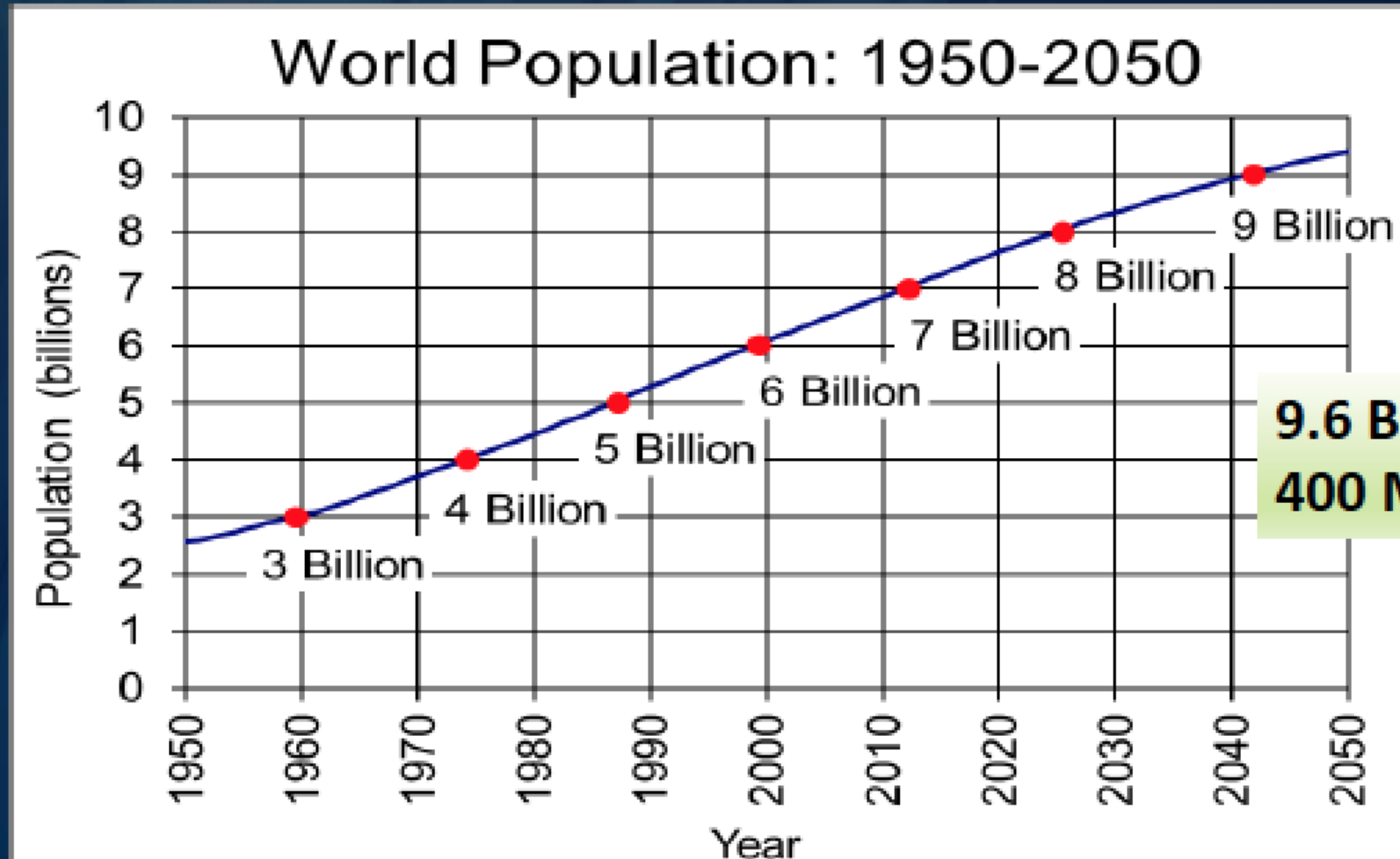
The WHO established guidelines for developing **diagnostic tests** adequate for developing countries and resource-poor settings, which are summarized under the acronym **ASSURED**





# Growing and Aging Population

In 2050, the population aged 65 and over is projected to be 83.7 million, almost double its estimated population of 43.1 million in 2012.\*

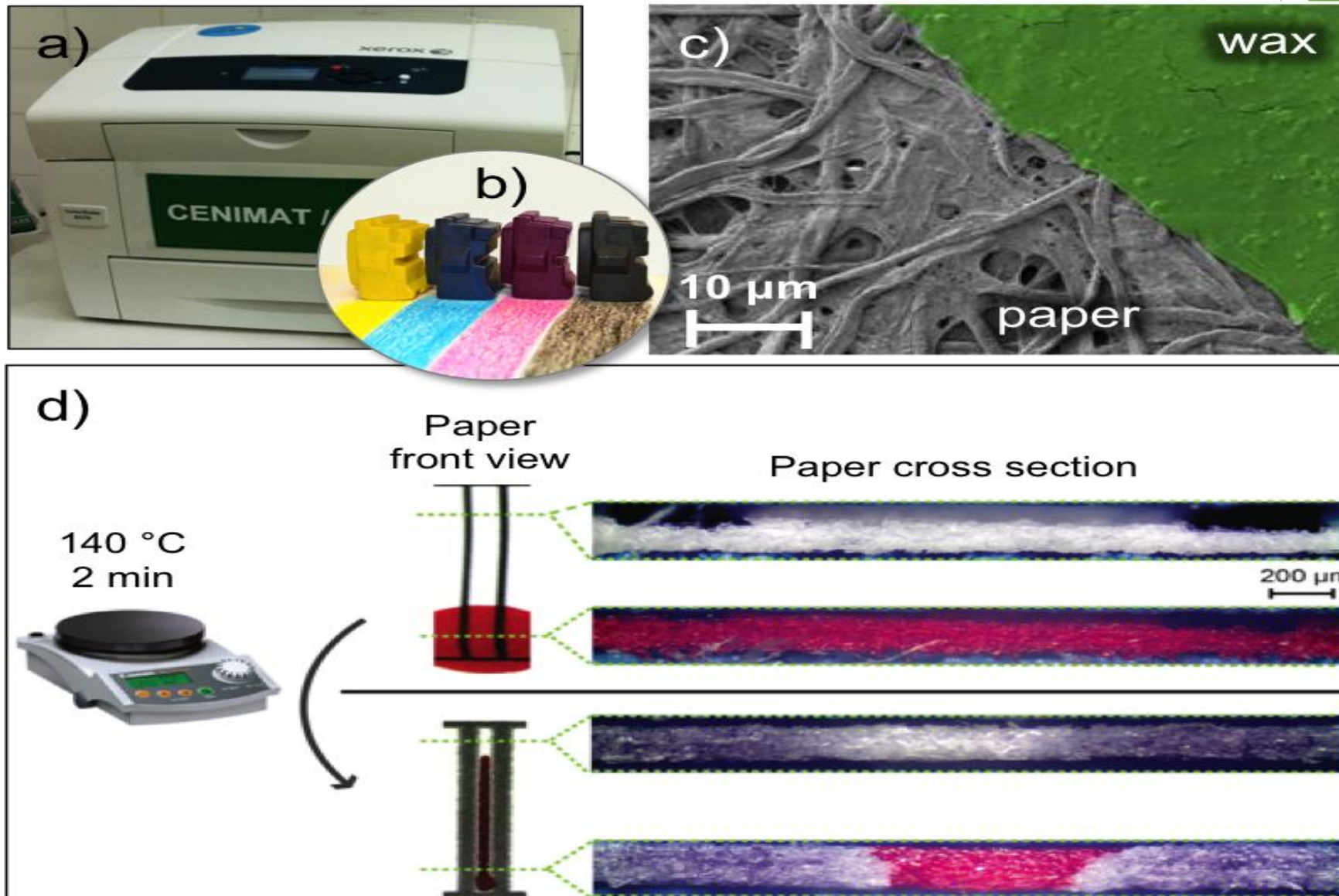


**9.6 Billion by 2050**  
**400 Million in U.S.**

Source: U.S. Census Bureau, International Data Base, July 2015 Update.

\*U.S. Census Bureau, May 2014

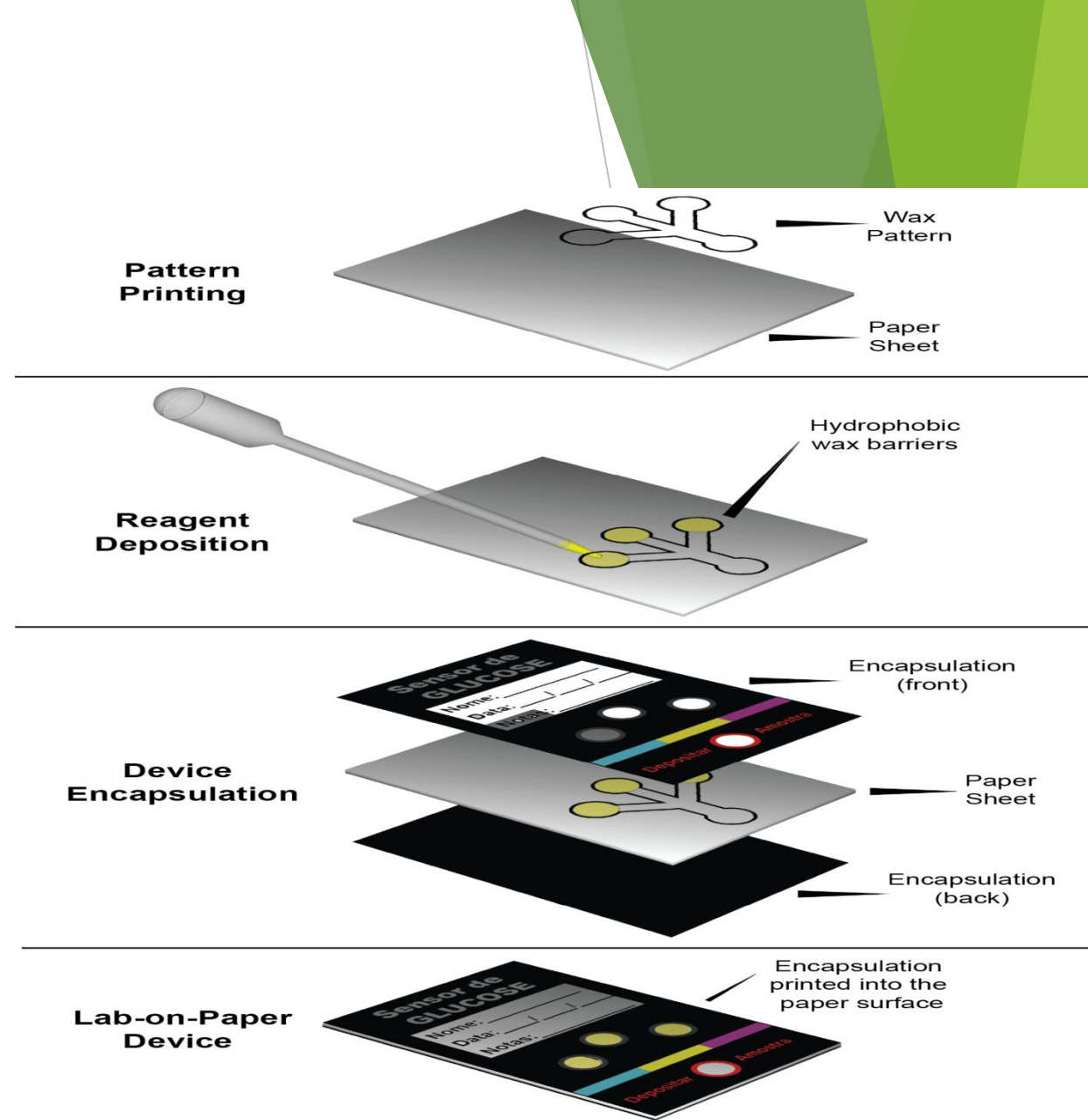
# Lab-on-Paper



# Glucose biosensor

## 1. $\mu$ PAD

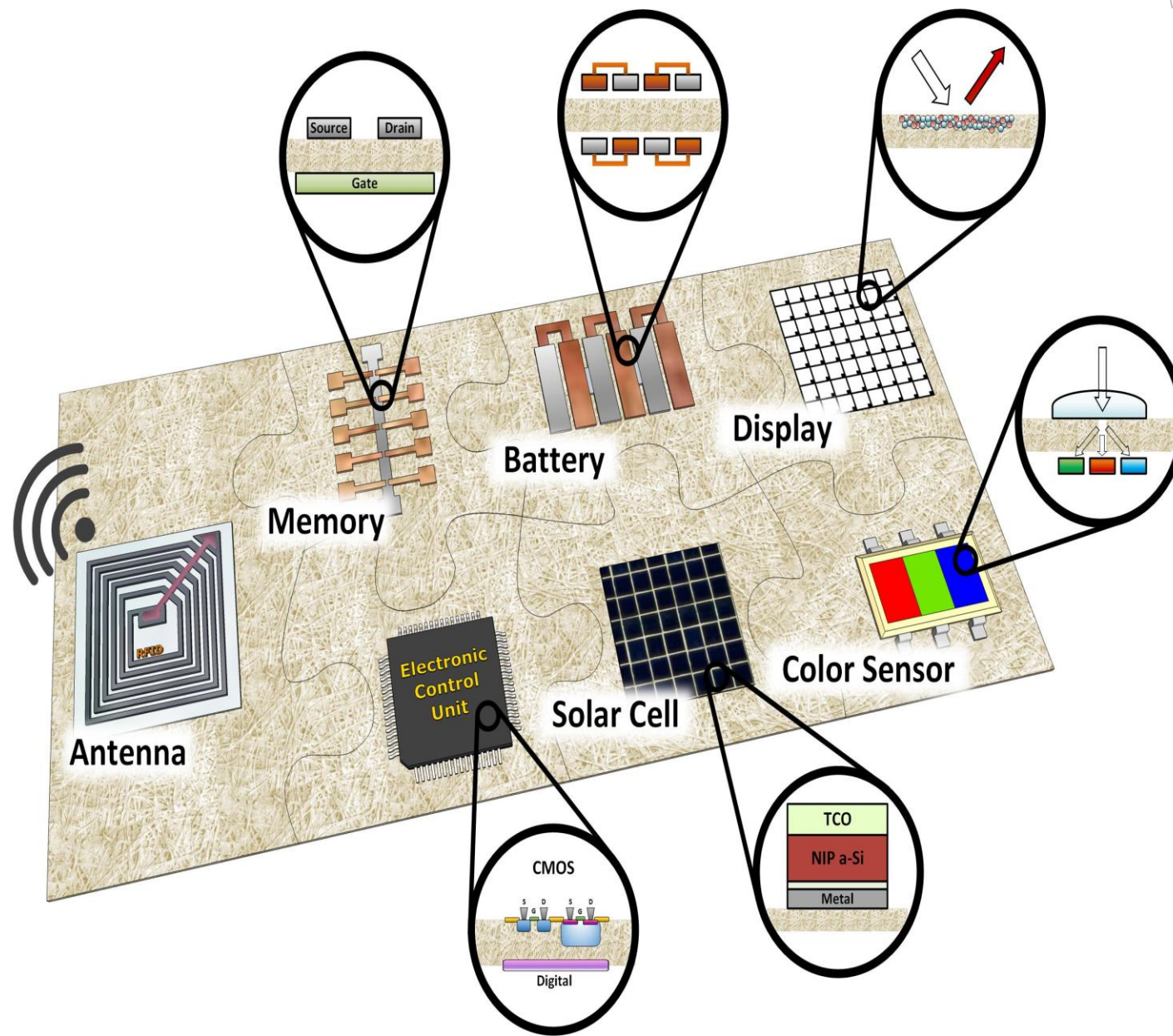
Paper Analytical Device



Costa, M. N. et al., A low cost, safe, disposable, rapid and self-sustainable paper-based platform for diagnostic testing: lab-on-paper. *Nanotechnology* 2014, 25, 094006.

# Conclusions

All Cellulose Devices



# Challenges/Opportunities

Healthcare

*(aging population)*

Water

Food

IoT

Paper → disruptive  
Applications

and

Applications → paper  
with more functions

## Requirements for Future Ubiquitous Electronics



- **Ultracheap/disposable**  
Scalable production of electronic inks
- **Seamless integration**  
Printable flexible electronics
- **Power management**  
Ultra low power electronics/  
Energy conversion/storage
- **Efficient wireless communication**  
High speed electronics/  
New devices for WIFI



**“If you want to go fast, go alone. If you want to go far, go together”**

# Acknowledgments - Current Projects

**FCT**

Fundação para a Ciência e a Tecnologia

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR



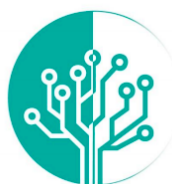
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roll-out



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MATERIALS SYNERGY INTEGRATION FOR  
A BETTER EUROPE



Symbiotic



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The event

The award

The finalists

2016

2015

2014

2013

2012

2011

2010

2009

# Elvira Fortunato and Rodrigo Martins (Portugal)

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RTP  
➤ Cientista portuguesa selecionada para prémio europeu

P3  
➤ Cientistas portugueses são finalistas em Prémio Europeu do Inventor





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RESEARCH

Elvira Fortunato, Rodrigo Martins  
Paper transistors