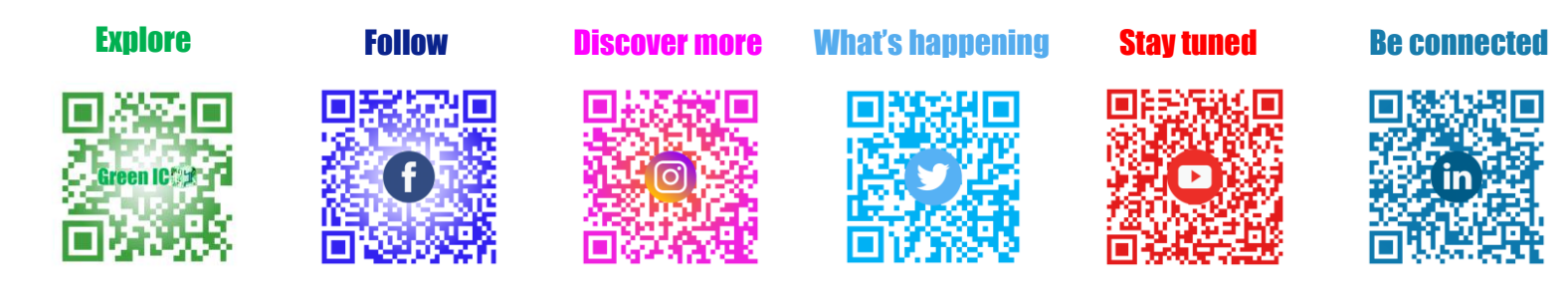


# E-Textile Battery-Less Walking Step Counting System with <23 pW Power, Dual-Function Harvesting from Breathing, and No High-Voltage CMOS Process

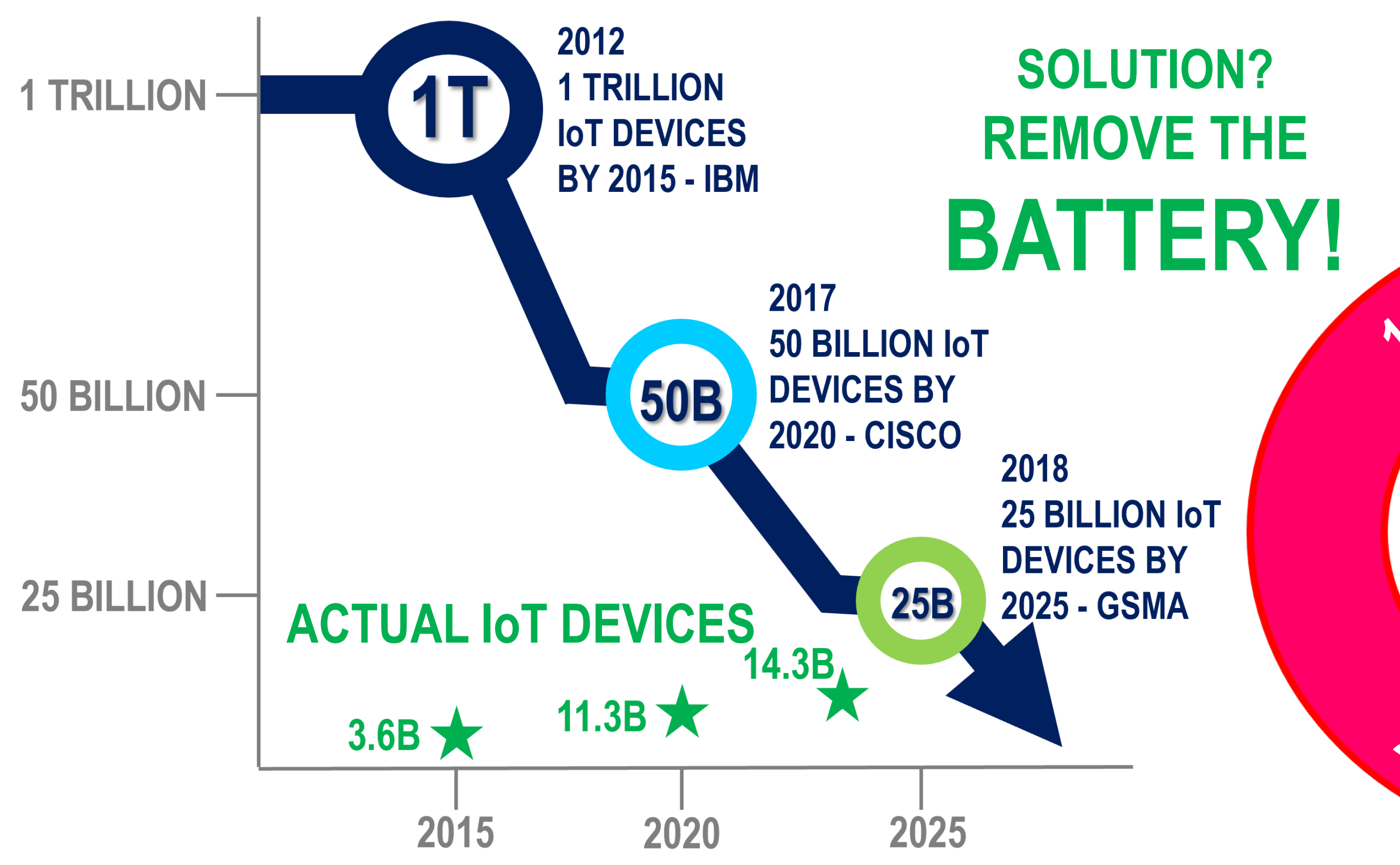
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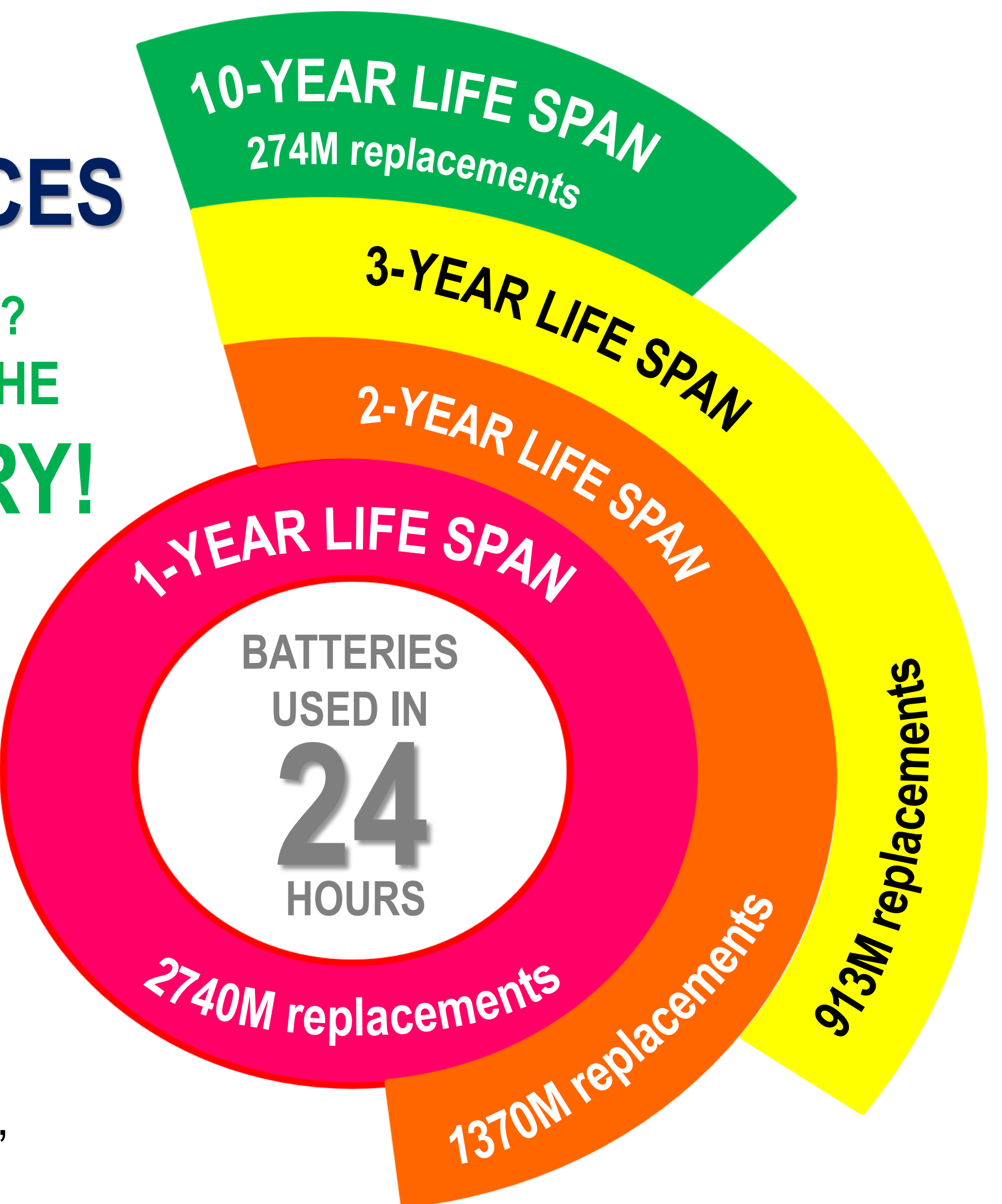


## Background & Motivation

### PREDICTED & ACTUAL IoT DEVICES



**SOLUTION?  
REMOVE THE  
BATTERY!**

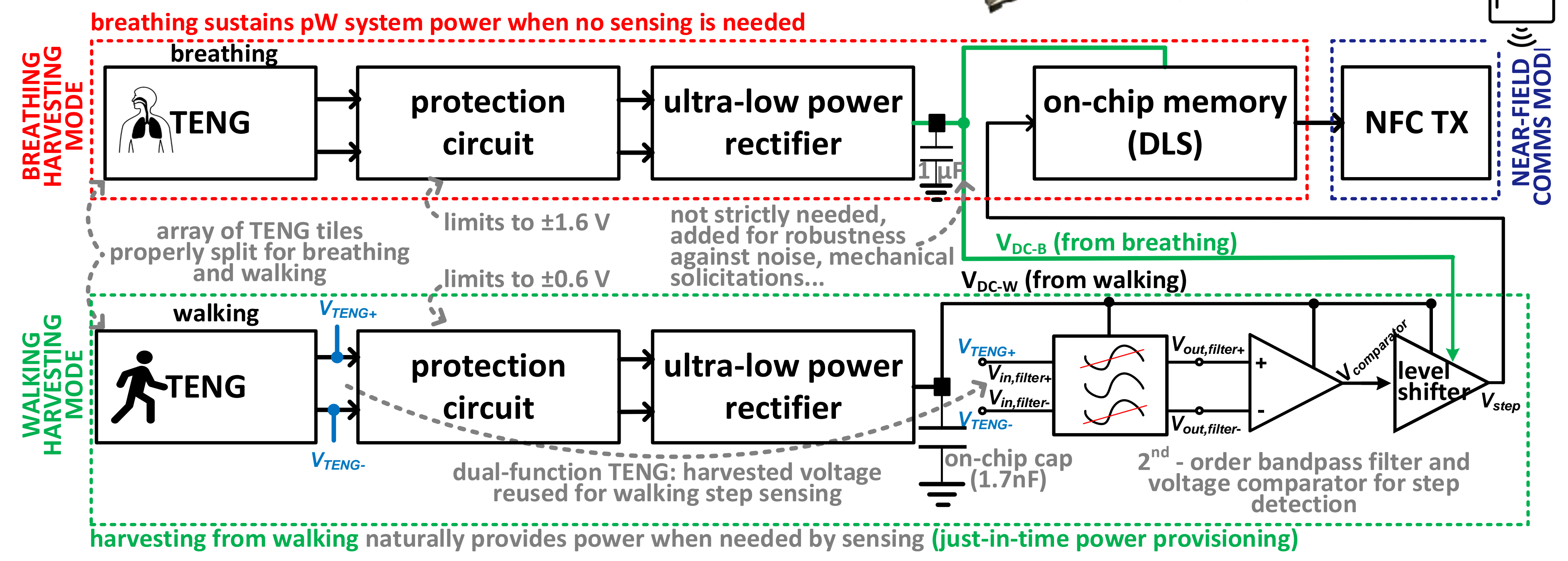
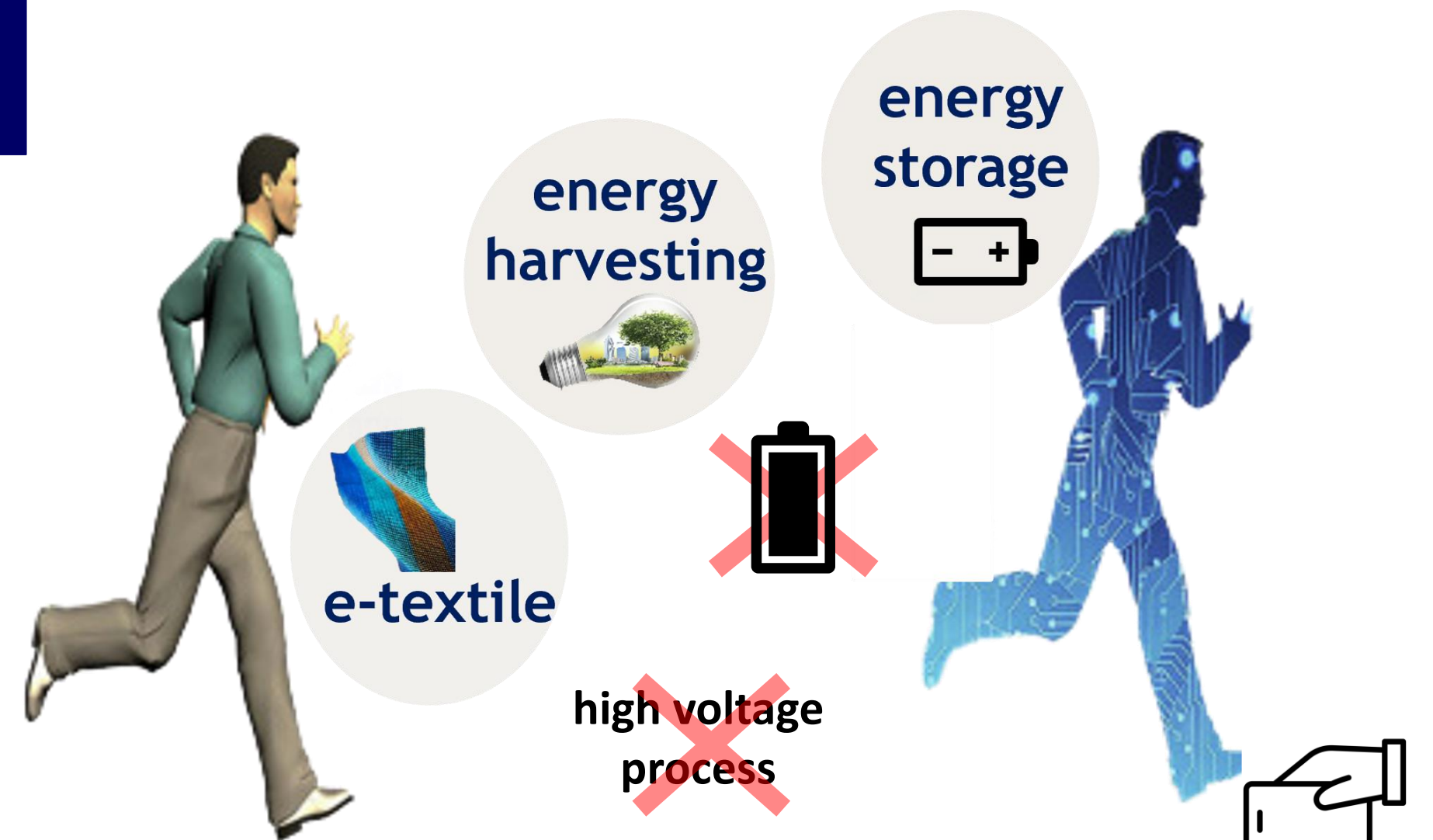


- The predicted number of IoT devices keeps decreasing,
- Problem : **Battery!**
  - 1 trillion sensor world demands: **913,242,009 BATTERY REPLACEMENTS** everyday
- Solution : **Self-powered systems**

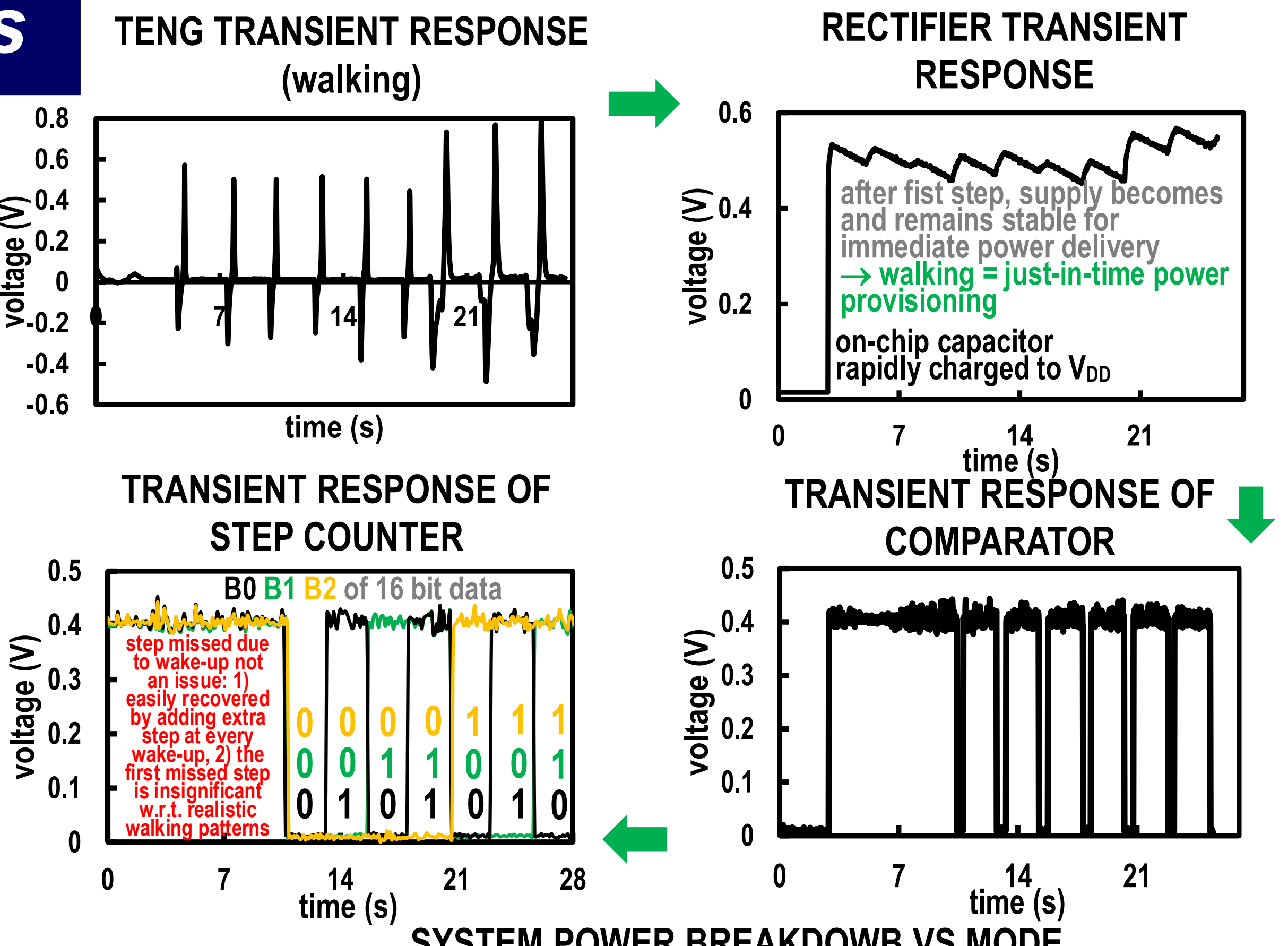
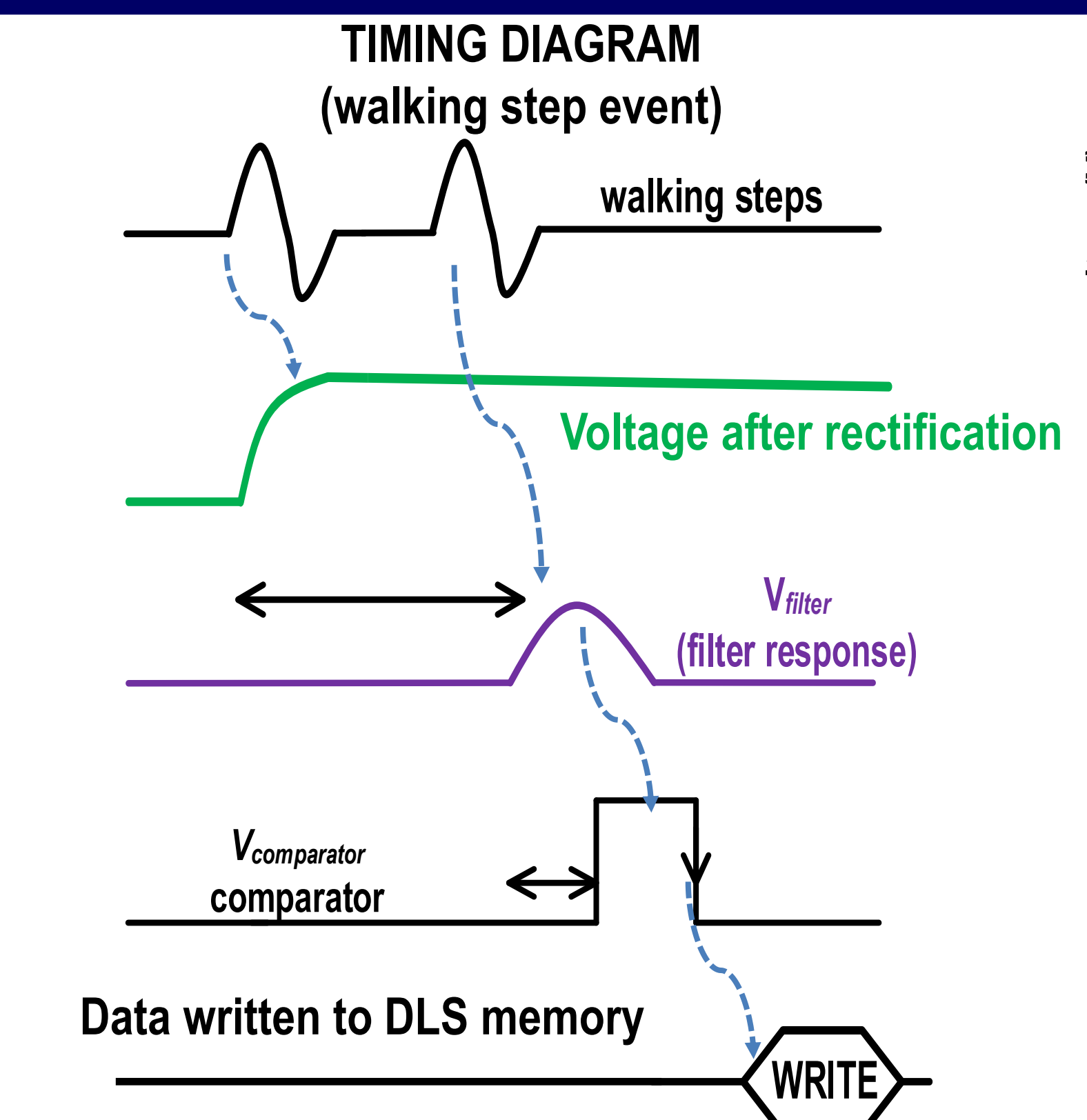
Source: Everactive report. available: [https://cdn.everactive.com/content/uploads/2019/06/17103828/EverActive\\_Infograph\\_1.pdf](https://cdn.everactive.com/content/uploads/2019/06/17103828/EverActive_Infograph_1.pdf)

## Scope of Work & Architecture

- Scope of this work:
- in-textile always-on walking step counter
  - energy harvesting from triboelectric nanogenerator (TENG)
  - lowest no. of in-textile and off-chip components (battery-less, inductor-less, and on-chip OV)

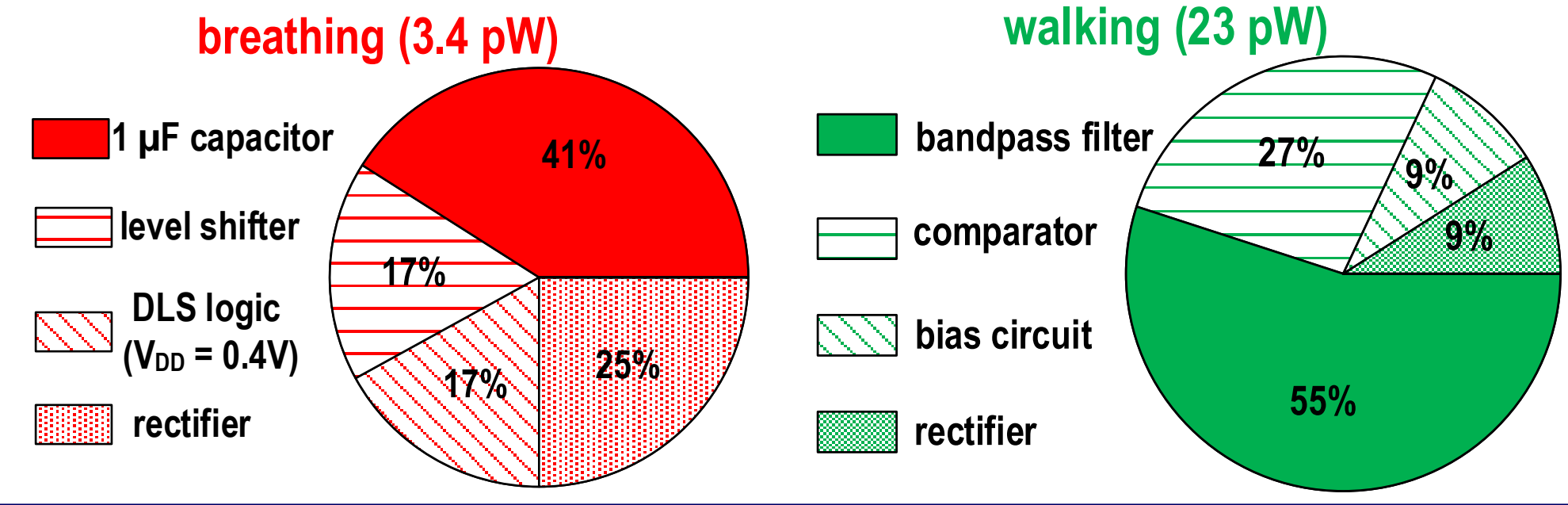


## System Measurements

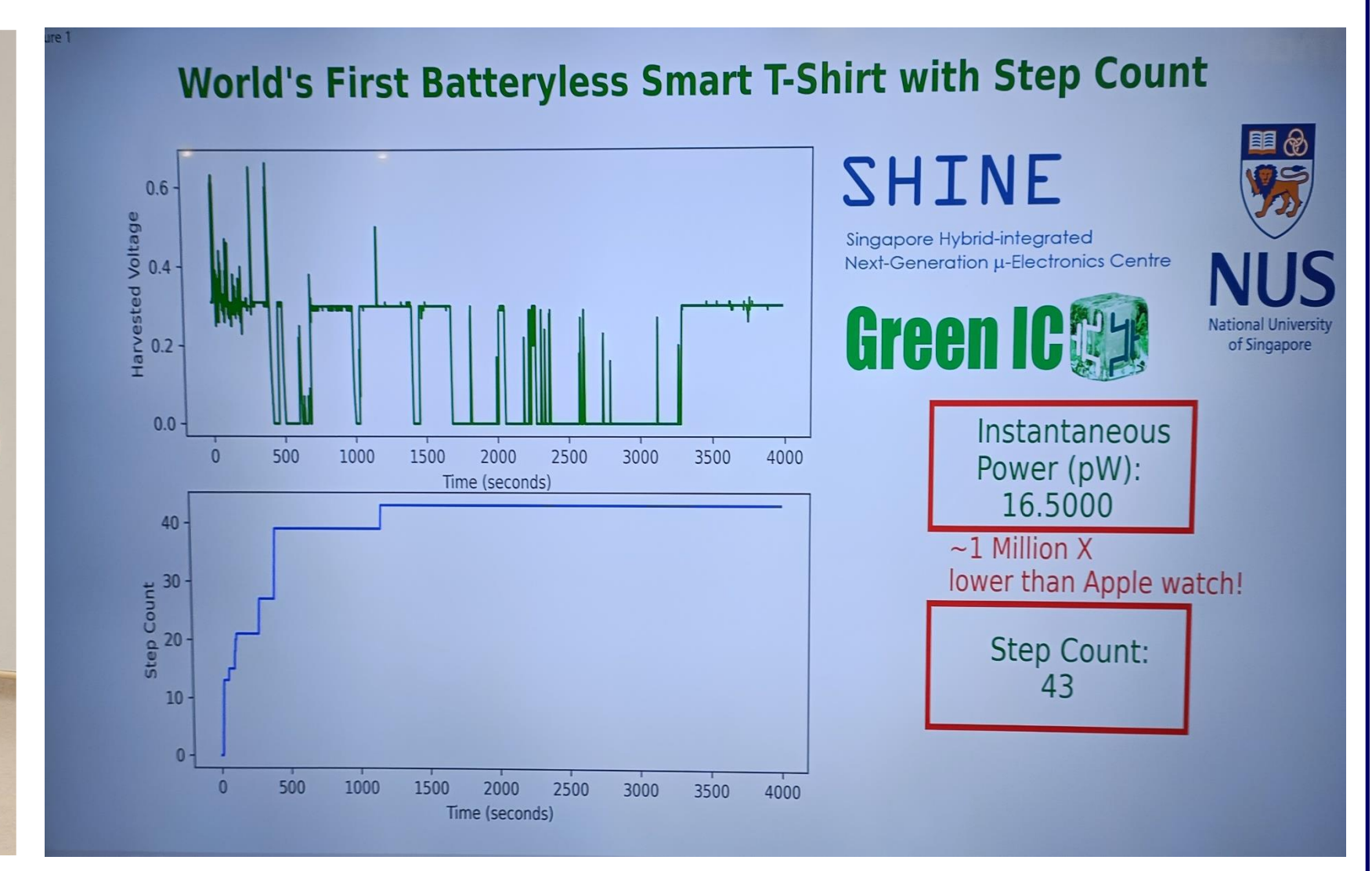
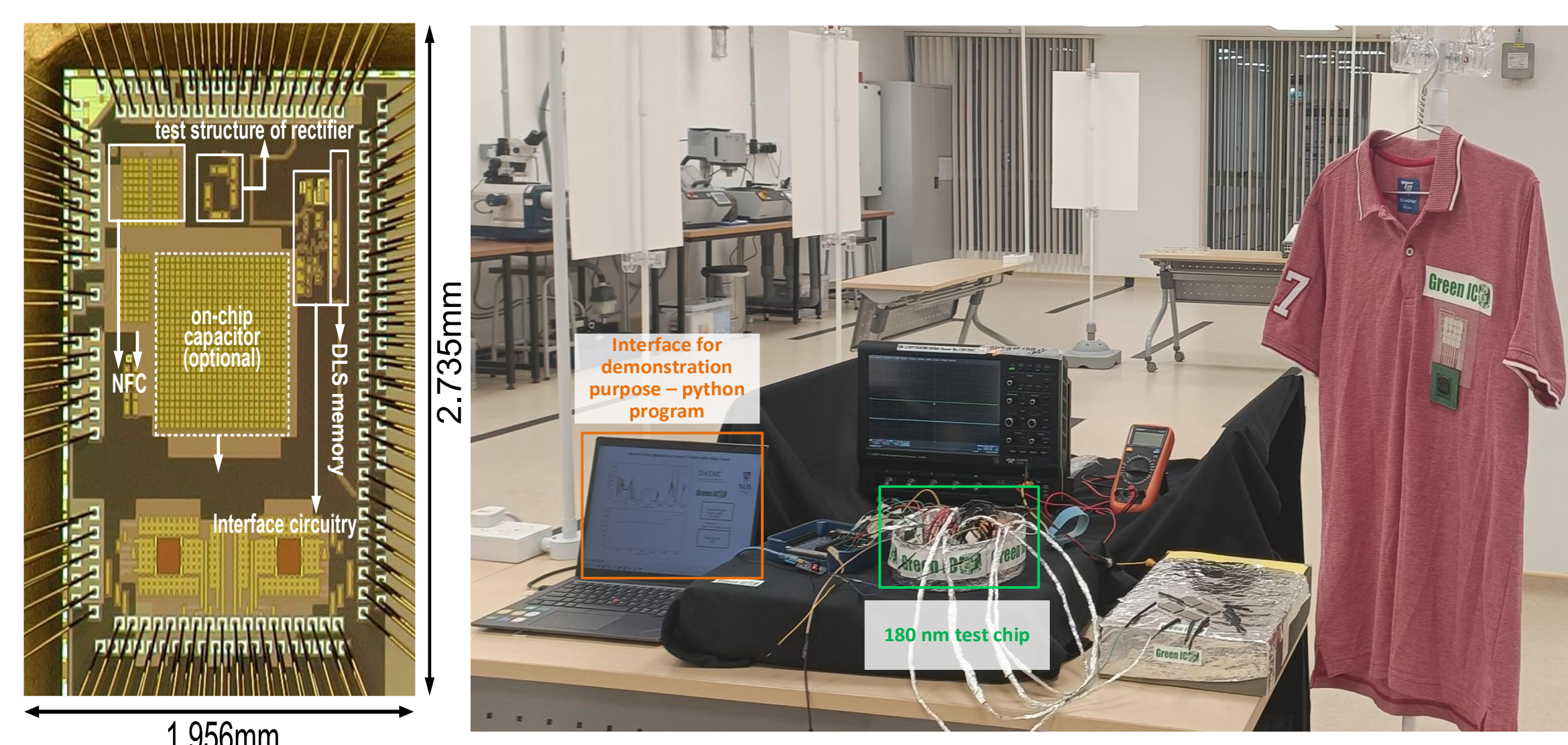


### Key achievements:

- lowest consumption (pW, 230X less than prior art) → always-on under any human motion condition including breathing
- battery-less end-to-end system demonstration



## Test Chip and Demonstration



	This work	JSSC'21	JSSC'19	JSSC'21	ISSCC'13	ISSCC'19	ISSCC'18
technology (nm)	180	180	180 BCD (HV)	180 BCD (HV)	180	350	40
area (mm <sup>2</sup> )	0.36 core + 0.68 cap (die-stackable)	0.81	5.91	1.69	1.46	1.9	0.55
type of system	step counter w/ harvesting from breathing / walking / motion	body temperature monitor	harvesting sub-system	harvesting sub-system (vibration)	e-textile body area network	harvesting sub-system (multi-axial motion)	harvesting sub-system (vibration)
energy harvester and substrate	low-voltage triboelectric (<3.3 V) e-textile substrate	triboelectric (4 V) flexible substrate	triboelectric (130 V)	triboelectric (36 V) rigid substrate	inductive RF	piezo-electric (1.6 V) rigid substrate	piezo-electric (6 V) rigid substrate
total power consumption (mode)	3.4 pW (breathing mode) 23 pW (walking sensing)	17.01 nW (temp. sensing) 5.21 nW (PMU)	N/A (harvesting only)	N/A (harvesting only)	2.9 mW (data transmission)	N/A (harvesting only)	N/A (harvesting only)
voltage before rectifier (V)	≤3.3 V <sub>pp</sub>	4 V <sub>pp</sub>	130 V <sub>pp</sub>	36 V <sub>pp</sub>	2 (after rectifier)	1.6 V <sub>pp</sub>	6 V <sub>pp</sub>
harvesting efficiency (mode)	63.7% (peak 80.2%)	N/A	70.7%	75.6% (harvesting mode)	N/A	84.6% (harvesting mode)	94% (harvesting mode)
sensing accuracy	>98% (step counting)	±1 °C (temp.)	N/A	N/A	N/A	N/A	N/A