Micro-Power Management and System Integration Considerations for IoT Edge Devices

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European Union
European Regional Development Fund

Opportunity

- 100 Billion connected devices, 1 trillion sensors by 2025[1]
- CAGR 12.6%, with spending forecast to reach $1.1 trillion in 2023[2]
- One Third of spend will be Commercial industries
  - Discrete Manufacturing
  - Process Manufacturing
  - Transportation
- Key Applications
  - Condition Monitoring
  - Energy and process efficiencies
  - Asset Tracking
- What's needed
  - Sensors and Actuators
  - Cost effective
  - Battery powered in many cases **especially the retrofit case**
    - Deploy and forget
    - Low maintenance

1. P. Diamandis, M.D. Singularity University, https://singularityhub.com/2015/05/11/the-world-in-2025-8-predictions-for-the-next-10-years/
2. IDC marketing report June 2019 https://www.idc.com/getdoc.jsp?containerId=prUS45197719

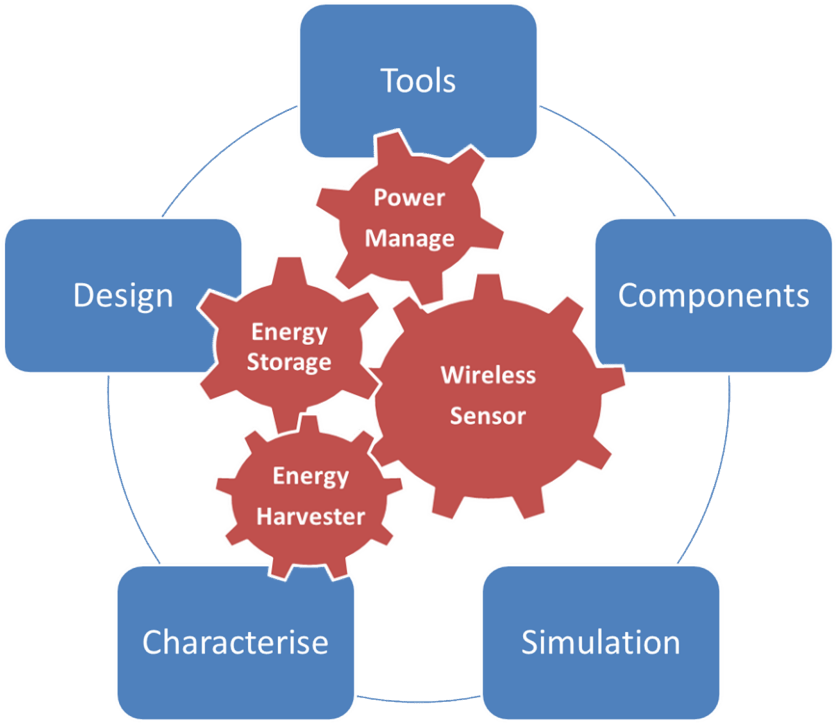
Challenges - Power

- Wireless, battery driven, deploy and forget sensors most suited to retrofit.
- Replacing batteries is expensive.
  - Cost of labour to replace
  - Cost and Impact of maintenance schedules
    - Production down time
    - Hard to access
    - Often replace batteries not yet depleted
  - Cost of battery
  - Environmental costs

- The power challenge
  - Autonomously power the wireless sensor from ambient energy.
  - OR to make the battery outlive the sensor.
  - WHILST at the same time ensuring a continuous reliable supply of power!

Challenges - Interoperability

- An energy harvested power system is a complex system
- To enable development of these complex systems a number of functions are required.
- Effective design requires all parts to be easily integrated, this requires standardised interfaces and models
- Enablers for interoperability
  - Standardised characterisation methods
  - Common simulation tools and interfaces
  - Common design methodologies
  - Standardised component libraries
  - Early collaboration



Focus of ICT4EE group at Tyndall

We supply solutions to help power the Internet of Things with particular focus on wireless edge devices

Technologies

- We are supplying some combination of
  - **Micro-power management/Energy Harvesting (EH)** platforms,
  - hardware system integration and
  - testbeds

  in several projects

Applications

- Energy Efficiency in Buildings and Micro-grids
- **Conditional Monitoring (CM)** of Machines, Equipment & Infrastructure
- **Asset tracking**

The following slides comprise

- Some tech insight into power management activities
- High level overview of system integration outputs
- Links and synergies with EU EnABLES project

Focus of Tyndall & EnABLES – The 'Power IoT' Challenge

Industry challenge:

How do we make the batteries outlive these 1 trillion IoT sensors?

Solution:

Collaboratively and concurrently develop application orientated & optimised solutions

- **Get academic and industry developers of energy harvesting components and systems as well as IoT devices to work together**
- **Accelerate & optimise development of parts and systems**
- **Parts should be standardised and interoperable**

Tyndall doing this via internal and external collaborations
External collaborations spearheaded by

EnABLES

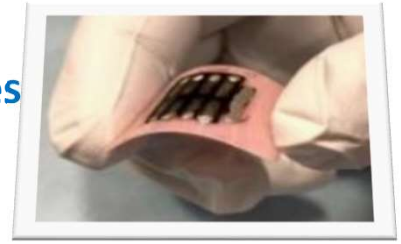
EU infrastructure project

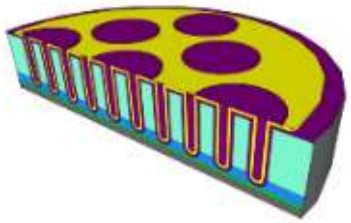
EnABLES

EU Project 730957

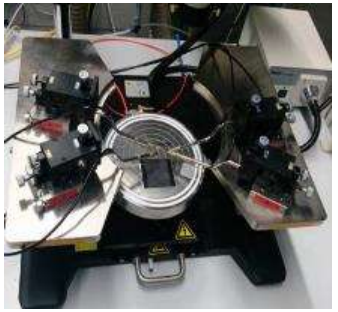
- Builds an ecosystem to power the internet of things
- Driving system level thinking & optimization
  - Via collaboration, inter-operability, standardization
- Its Transnational Access program* gives
  - Free of charge access to expertise & laboratories
  - Feasibility studies

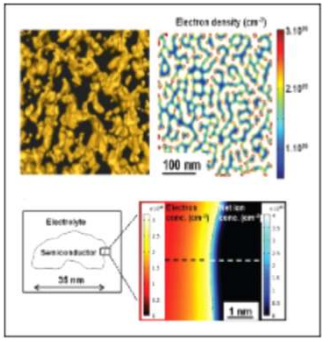
  (paper, simulation, characterisation, proto)
- Sign Up and enquire at www.enables-project.eu





- Joint Research Activities* are creating
  - System optimised, application orientated solutions
  - De-risked & standardised methodologies & library parts





* Open to industry and academic applicants worldwide

** Done by project partners listed below

Tyndall National Institute · Fraunhofer · cea · imec · KIT · Politecnico di Torino · NiPS Laboratory Noise in Physical Systems · Alma Mater Studiorum Università di Bologna · University of Southampton

Sample Access projects

EnABLES-003

Thin film batteries at CEA-Leti

EnABLES-004

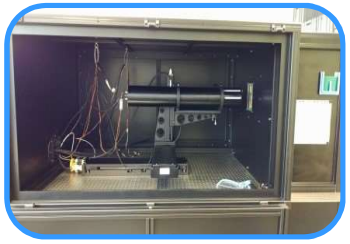
RF energy harvesting at Fraunhofer IMS

EnABLES-005

Stacked micro batteries at CEA-Leti

EnABLES-006

Low power animal tracking at Fraunhofer IIS

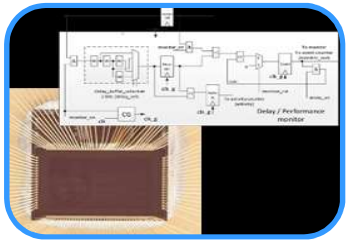


EnABLES-009

PV energy harvesting at Fraunhofer IIS

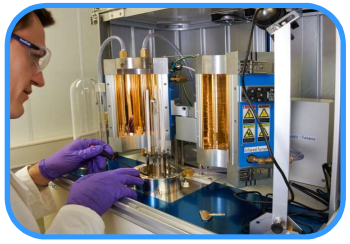
EnABLES-015

Electrochemical micro batteries at Tyndall



EnABLES-017

ASIC for Vibrational EH at imec-NL



EnABLES-025

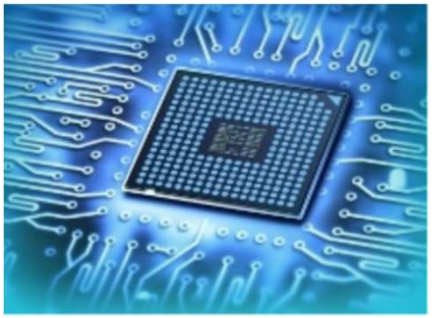
Improve thermoelectric performance at CEA-Liten

More can be found here
https://www.enables-project.eu/stories/

Note:- We also provide VIRTUAL ACCESS to a repository for ambient energy sources from Universities of Perugia (UNIPG) & Southampton
https://www.enables-project.eu/offer/virtual-access/

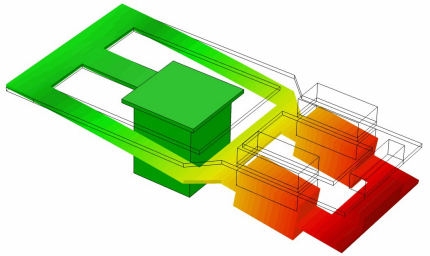
Where does Nanotech fit?

- Lots of More than Moore and system level cross cutting technologies….
- Improve performance of transducer and storage devices
- Several examples of work underway in EnABLES JRAs – ref . next slide
  - IUNET members UNIBO, UNIPG & POLITO involved (different departments)
- No direct benefit in moving away from standard CMOS for PMICs except for niche applications – external components much bigger than PMIC
- Any work that could help reduce size of external parts and MEMS devices/systems would help – e.g. capacitors, magnetics, sensors, antennae
- Any work that reduces power consumption of devices, esp. sensors
- Anyone doing low power air quality, internal motion or occupancy detection?
- Any suggestions that help us increase generated power and reduce consumed power are welcome!



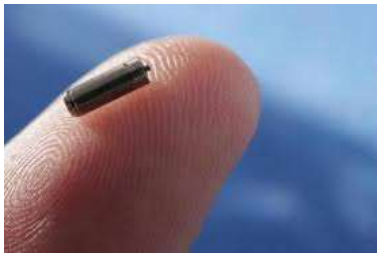
Some EnABLES JRA Activities

Energy Harvesting (EH)

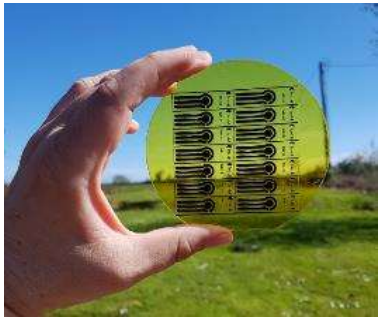


- **Wide-band non-linear vibrational harvesters**
- **Fabrication of a fully integrated MEMS Electromagnetic Vibration Energy Harvester**
- **Modeling and characterizing nonlinear wideband MEMS electrostatic Vibration Energy Harvester & investigate its integration with electrets.**
- **Novel high-performance thermoelectric materials & simulation models**
- **New integrated technique to measure anisotropic components of Seebeck coefficient, electrical and thermal conductivities**
- **Increase efficiency of amorphous silicon solar cells on 8'' wafers**

Energy Storage (ES)



- **Nanoscale materials that yield high-rate fast charging and discharge**
- **Enhancing cathode stability to increase the energy density**
- **Nanoscale protective films via ALD/CVD for higher energy density electrodes & improved lifetime**
- **Sulphur-based cathodes with x10 higher theoretical energy capacity**
- **Room temperature ionic liquids & new solid-like, solid-state and hybrid composite solutions**
  - **– improve thermal, ion transport & safety features of electrolytes**
- **ALD/CVD deposition of protective materials -higher energy/power density, lower cost, long life**
- **High entropy oxides (HEO) - promising new material class for electrode materials.**



Our Ecosystem of Stakeholders

Developers

Integrators

Suppliers

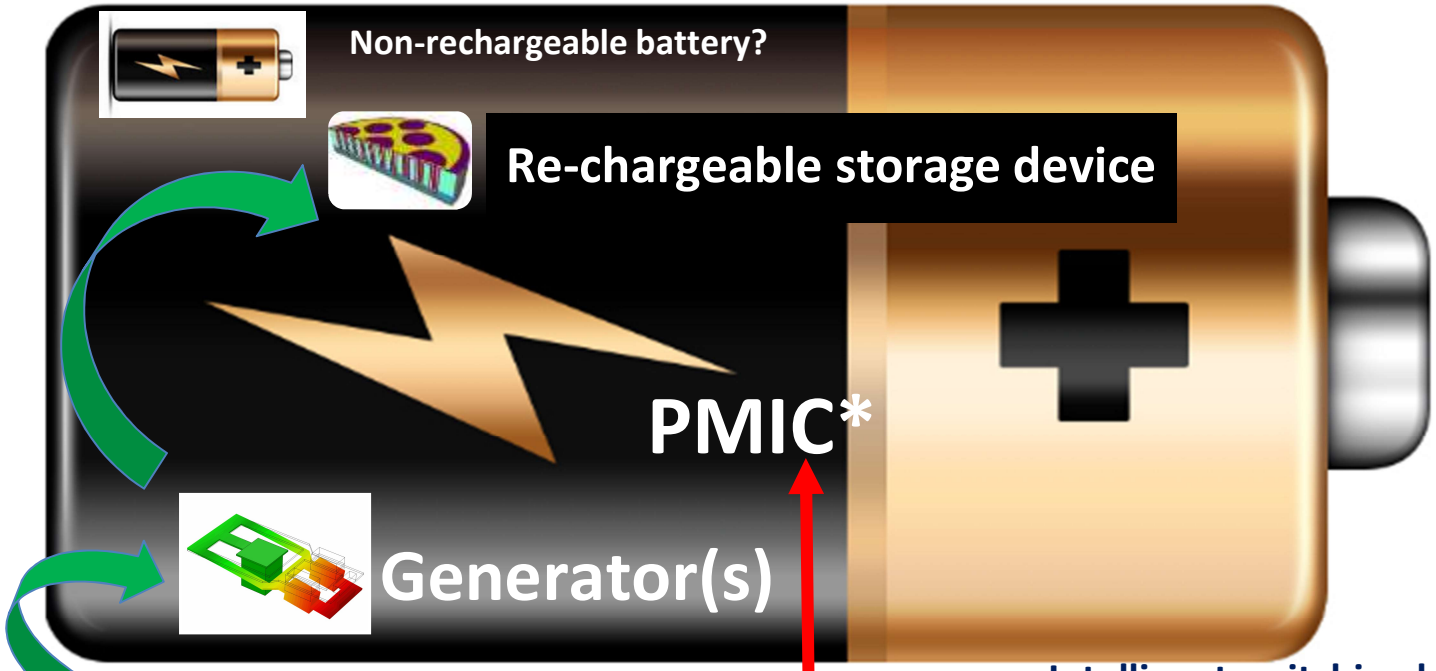
Users

Presented at EnerHarv 2018

Technology - Energy harvesting

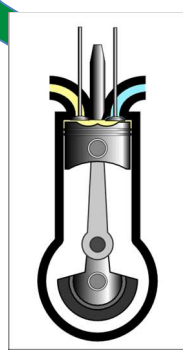
Replacing the function of a battery is not easy

- Complex array of stuff to be integrated



WSN Load

Sensors + Interface
Microcontroller
RF

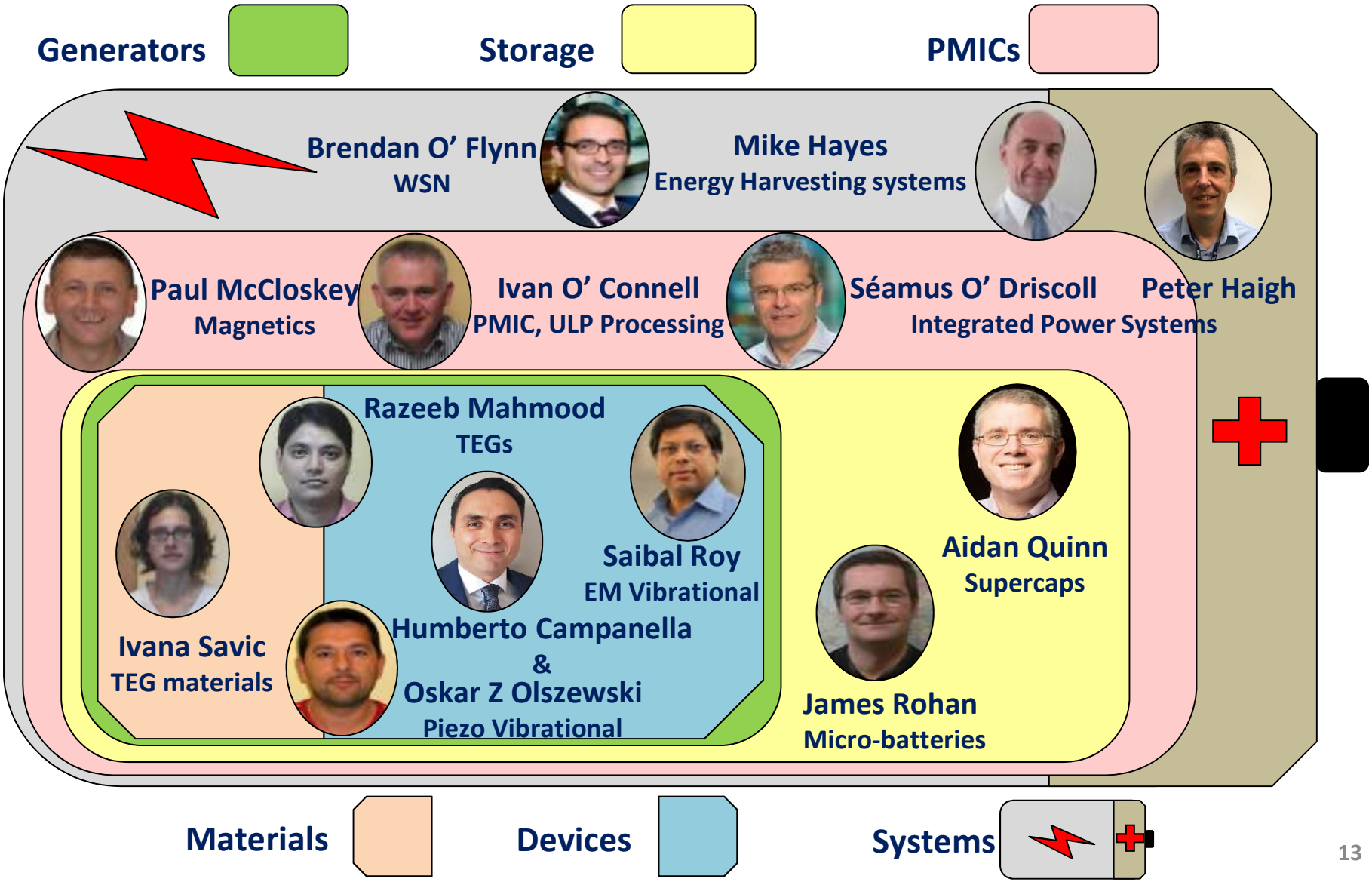


Ambient energies
(sporadic, low power levels)

Intelligent switching between ambient energies + battery + storage devices
Cold start
Voltage conversion
Impedance matching
Charge management
Peaks, transients
Status monitoring

*Power Management IC

Tyndall has an Ecosystem of PIs to address this

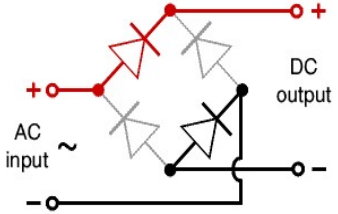


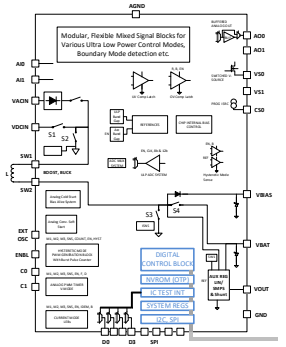
A One Stop Shop -
Tyndall Energy Harvesting & Storage

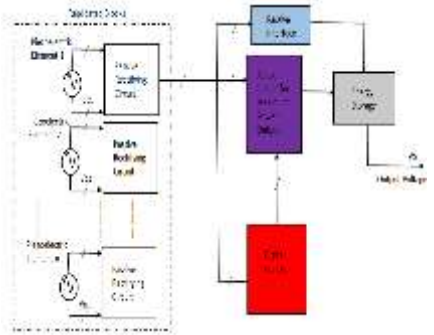
Tyndall National Institute
Instituiid Naisiunta

Control

Power Management ICs & Circuits
Multi-source
Self-start
High efficiency

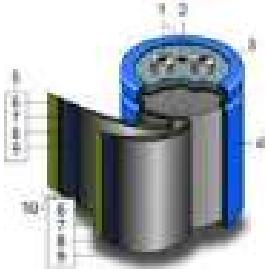


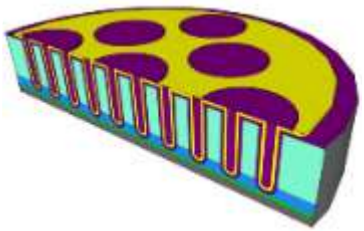


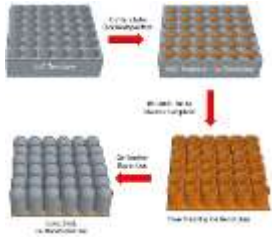


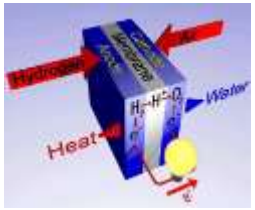
Storage

Supercaps on Silicon
Flexible batteries
Micro-batteries
Nanotube high density



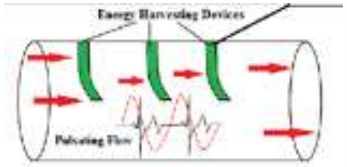


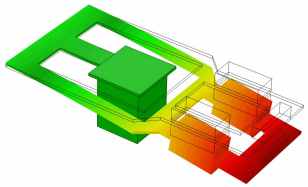


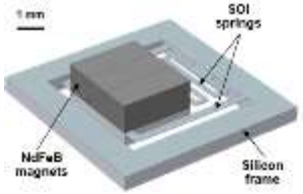


Generation

Generators on silicon
Wide bandwidth vibration
(Electromagnetic & piezo)
High density MEMS
IC integrated highest efficiency TEG materials

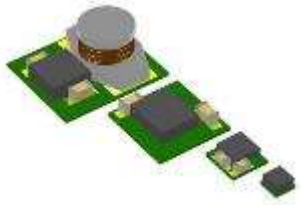


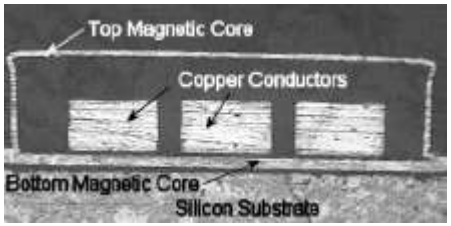


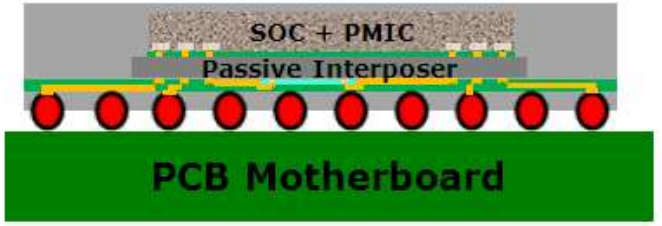


Material, Device & System Integration

Embedded Magnetics

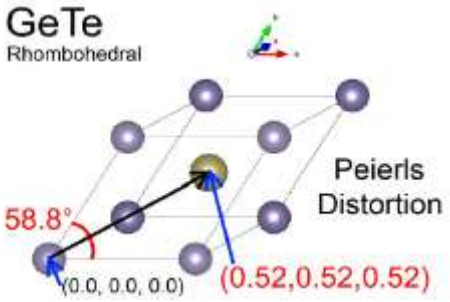




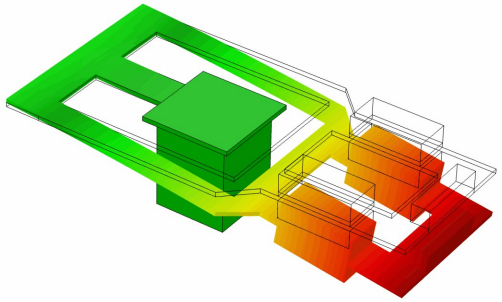


Making magnetics disappear in packages (PSiP) & onto ICs (PwrSoC)

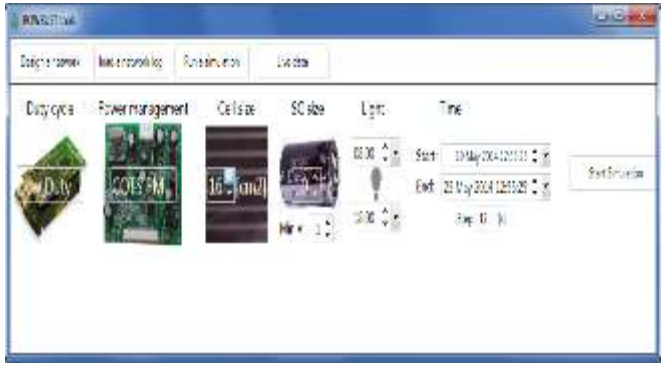
Simulation



Atomic/material



Physical/mechanical

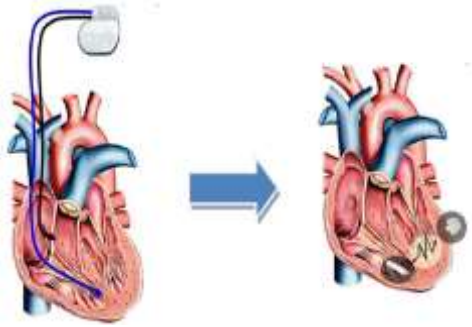


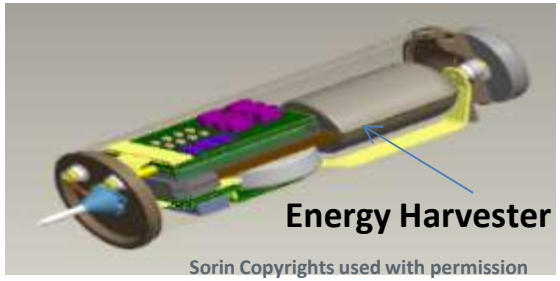
Design/Deployment tool
Circuits (discrete & CMOS)

The Power of Collaboration

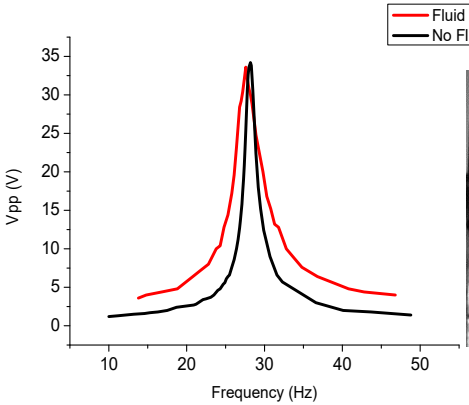
System application optimised parts & devices e.g.
Harmonise methodologies & specifications
Compatibility:- Process, Electrical, Packaging

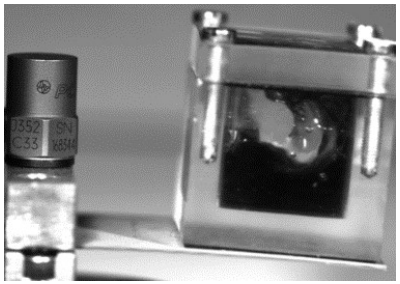
Some Application System Integration Examples

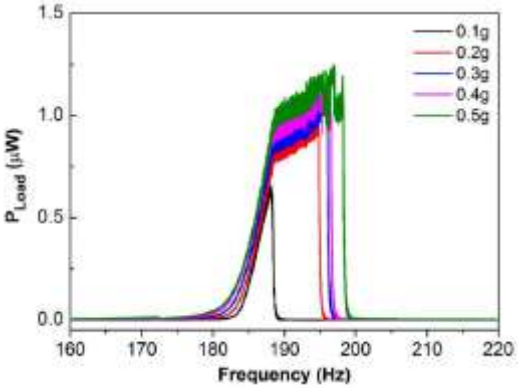


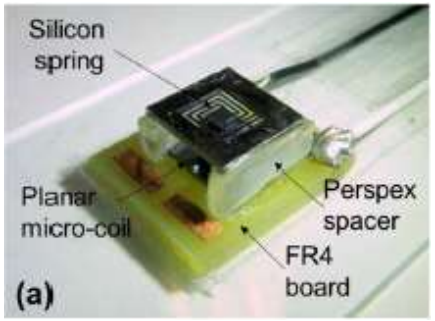


Miniaturisation:- Implantable Energy Harvester

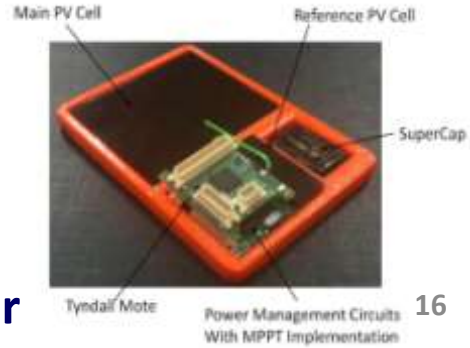








Performance enhancement:- Wide bandwidth Vibrational Energy Harvesters



Circuit and system innovation:- Indoor solar energy harvester

"MISCHIEF"
Multi-source energy harvesting PMIC

Highest efficiency switch-mode, energy harvesting PMIC, measured @ 10 µW point

- Cold-start and operation over ~1uW to 200mW

Lowest quiescent current (I_Q) in low power regulation mode, <200nA

Highest **end-to-end system** efficiency

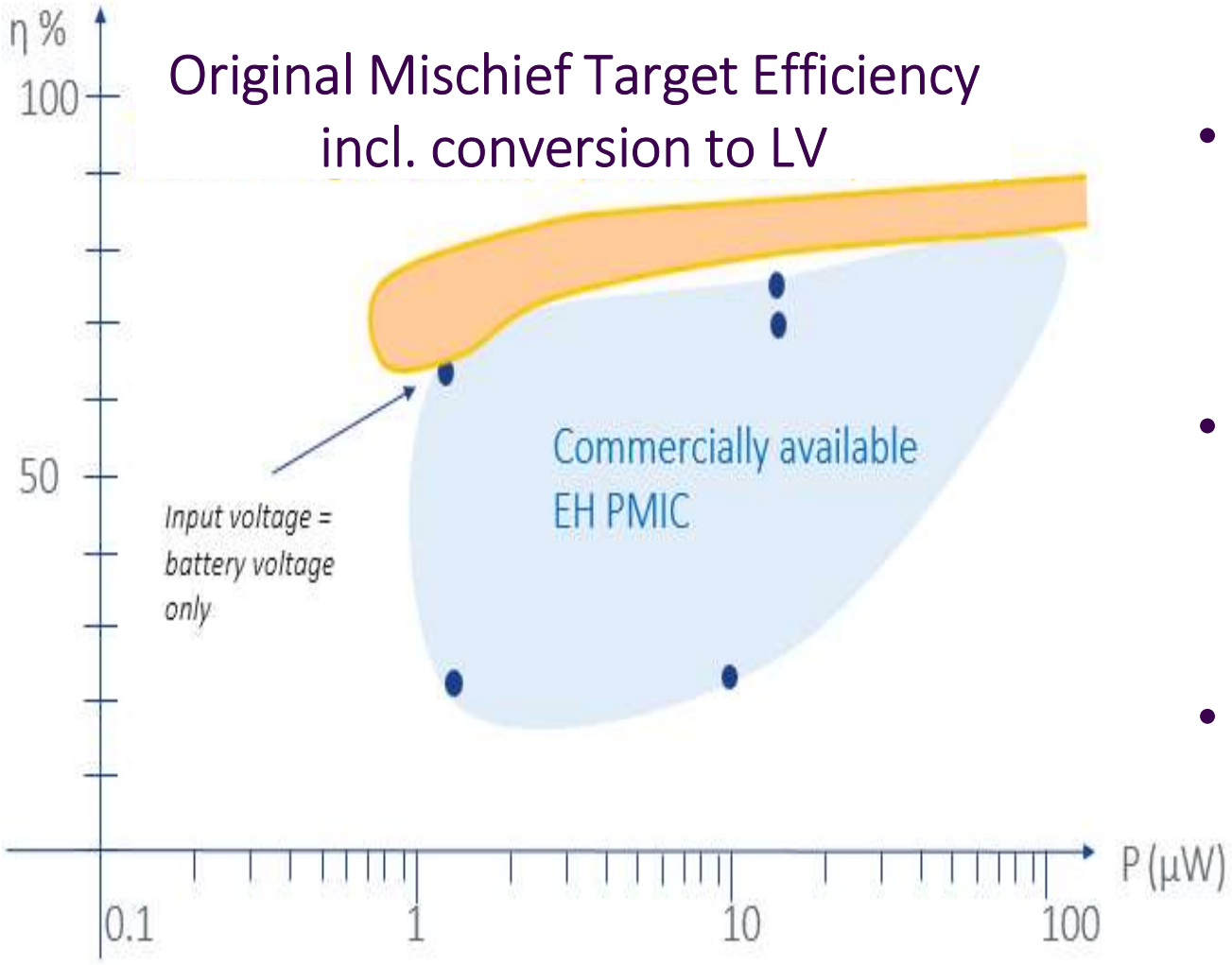
- Uniquely beginning with both ***Boost and Buck*** modes to both battery voltage (~3V) and LV (~1V8)

Technology Platform proofed for **FAST TRACK LOW RISK** development of:

- Next Gen control & features
- (Very much with ***mixed signal*** control approaches)
- Substantially increased power transfer – Vibrational Energy

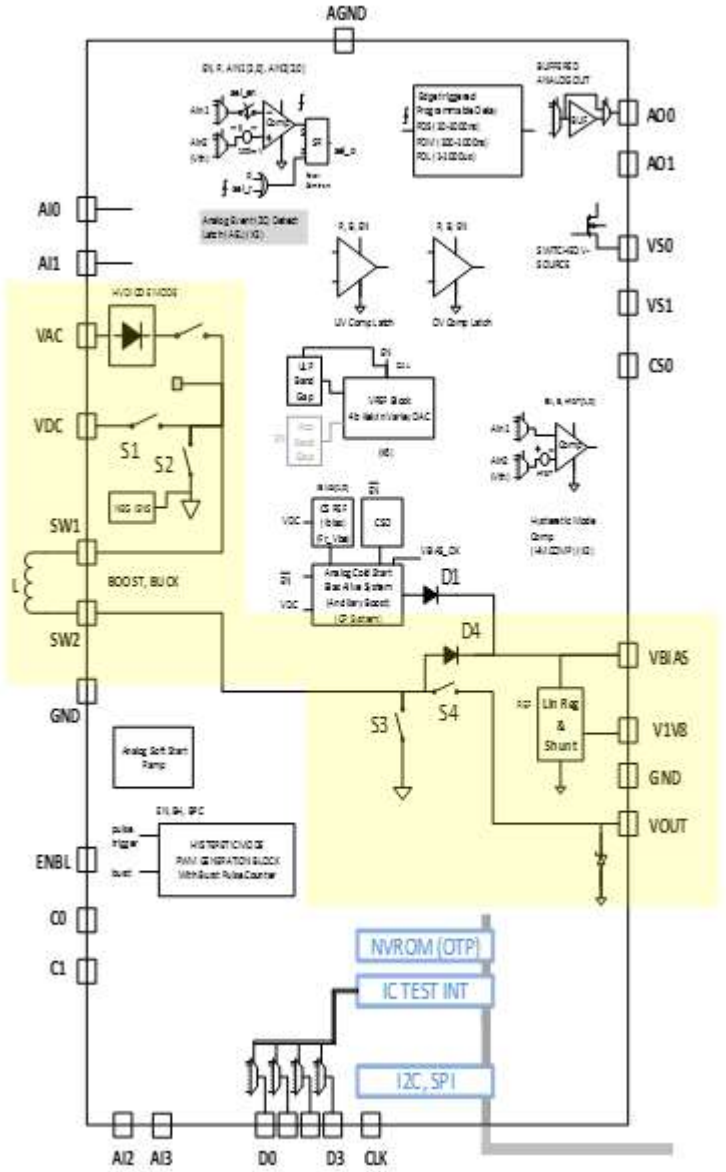
Not just for energy harvesting, also for any low power application, particularly good at interfacing with 'smart switching loads' to extend battery life

Highest Efficiency & Next Gen Capability



- 4 Switch Quasi Resonant Buck-Boost topology
- After extensive survey of best available parts
- Highest end-end efficiency over 1uW to 100uW

Mischief Gen. 1 Platform Block Diagram



- Modular Flexible Mixed Signal blocks
- Asynchronous and Analog
- Dynamic Power/Speed Control
- Fast Start and Stop Blocks – Efficient Duty Cycling

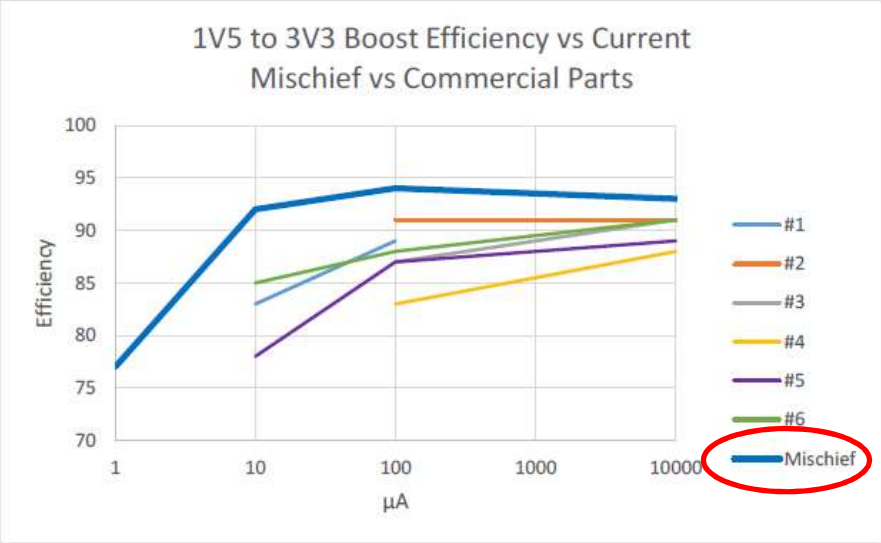
A platform strategy – interface with Microprocessor or FPGA and will be used for digital state machine development

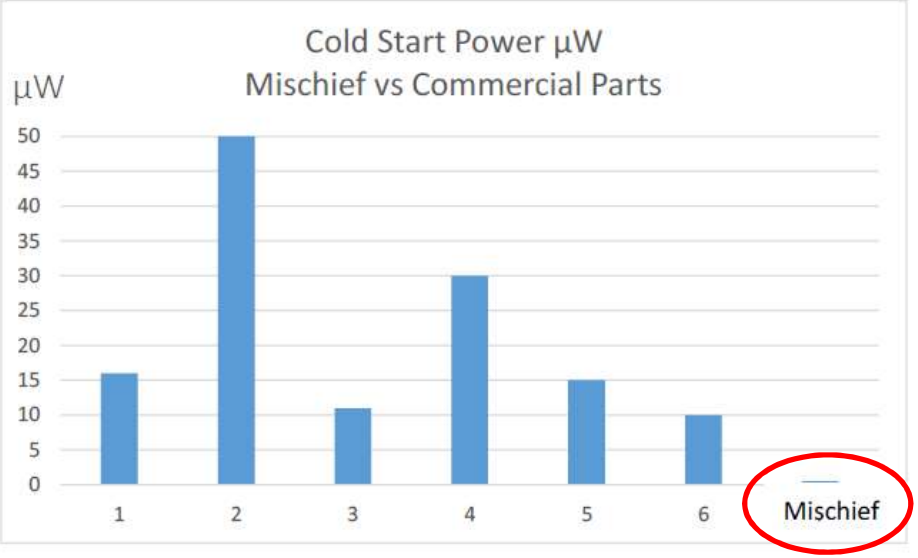
"MISCHIEF"
Gen 1. Results presented at EnerHarv 2018

Comparison with commercial parts…. 2018

World leading in efficiency, power range, voltage range and quiescent current

Only one part surveyed has buck-boost capability
None have advanced digital configurability (SPI)





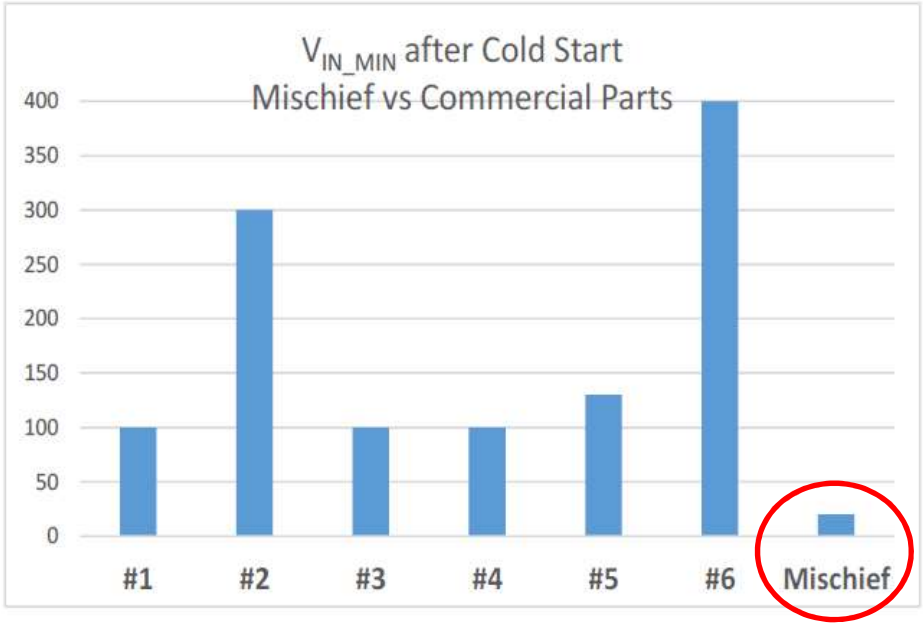
Mischief based on Top Level Schematic Sims (not LVS)

Part nos ADP5090, MB39C831, AEM10940, SPV1050, BQ25504, MAX17220

EnerHarv 2018

"MISCHIEF"
Results presented at EnerHarv 2018

Low Vin operation after cold start



Marketplace EH PMIC	SPI/ I2C Interface with Host WSN Controller	Topology	Low Output Voltages
#1	No	Boost	No
#2	No	Boost	No (3V+)
#3	No	Cascade Boost, Buck+LDO	Yes
#4	No	Boost, Buck-Boost, LDO	Yes
#5	No	Boost	No (2V+)
#6	No	Boost	No
Mischief	Yes	Buck-Boost	Yes (1V+)

"MISCHIEF"
Capability presented at EnerHarv 2018

Tyndall National Institute

MCCI Microelectronic Circuits Centre Ireland

Examples of technology block available

- 4 Switch QR Non Inverting Buck-Boost Power Path for 95% efficiency from 1uW to 10mW
- Mixed signal innovative architecture
- Extra low input voltage operation
- Asynchronous PWM Modes Generation
- Ultra efficient power path, gate drives and level shifters design
- 20nA Voltage Comparator
- 10ns Current Input Comparator
- 10ns High Side Voltage low voltage threshold Comparator
- Starved Inverter Ring Oscillators
- <100nA Cold Start: Oscillator/Charge Pump/Fractional reference system
- SPI Master Configurable Mixed Signal (external Serial EEPROM)
- High speed analog event detect latches (power cycleable)
- Variety of Digital-to-time converters (DTC)
- Ultra Low Energy ADC Systems
- Asynchronous master control state machines
- .....

EnerHarv 2018

MISCHIEF - What's next?

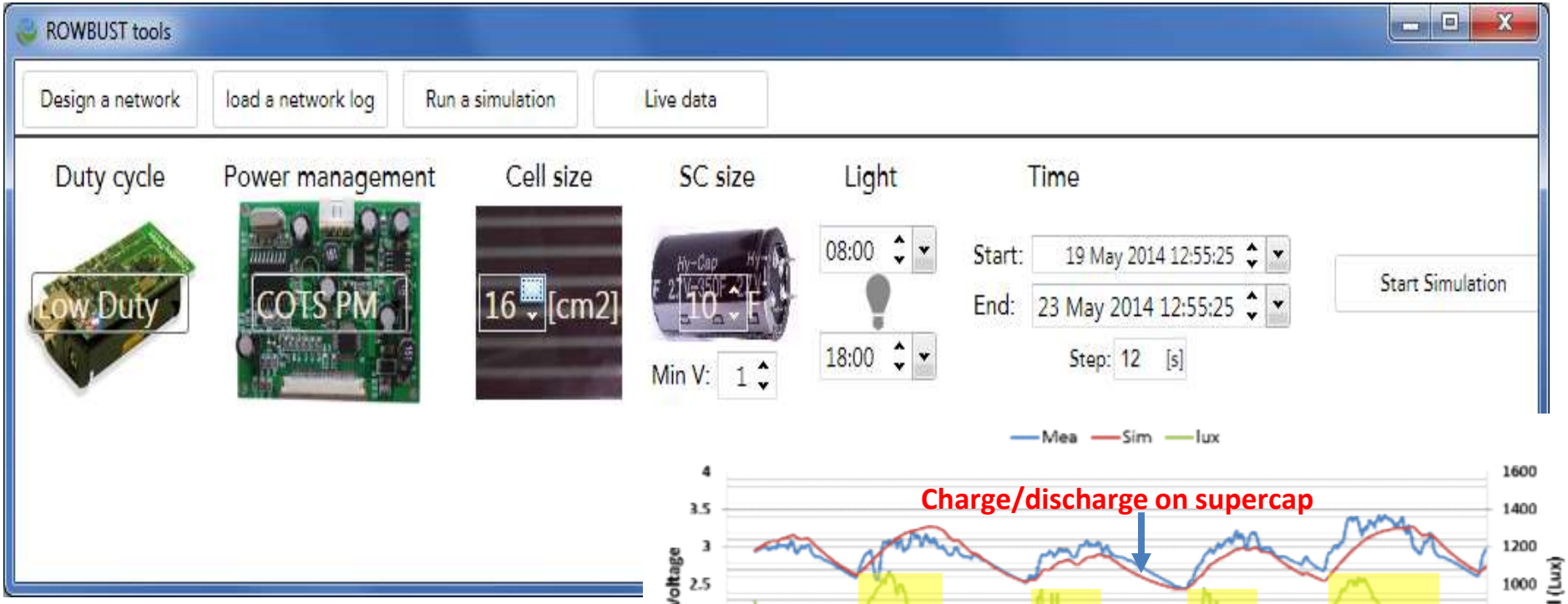
- Expecting receipt of 1st Si samples in Oct – verify simulation results
- Developing variant for med tech applications (Irish government funded project HOLISTICS)
- Planning to develop a system on chip combining MCU & PMIC functionalities
- Developing lots of circuit block for energy harvesting and storage developers under EnABLES JRAs and TAs to improve system level performance
- Preparing plans for 2nd generation development

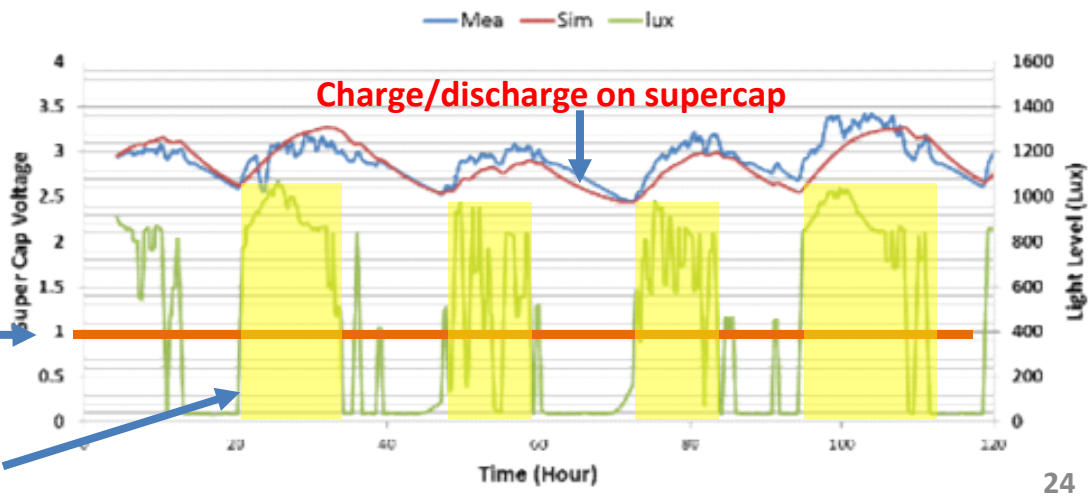
- Always interested in finding new collaborations, feel free to contact me

RoWBUST Battery life Assistance Tool

Help installers select hardware components for a potential energy harvesting deployment

No Energy Harvesting or wireless sensors expertise needed



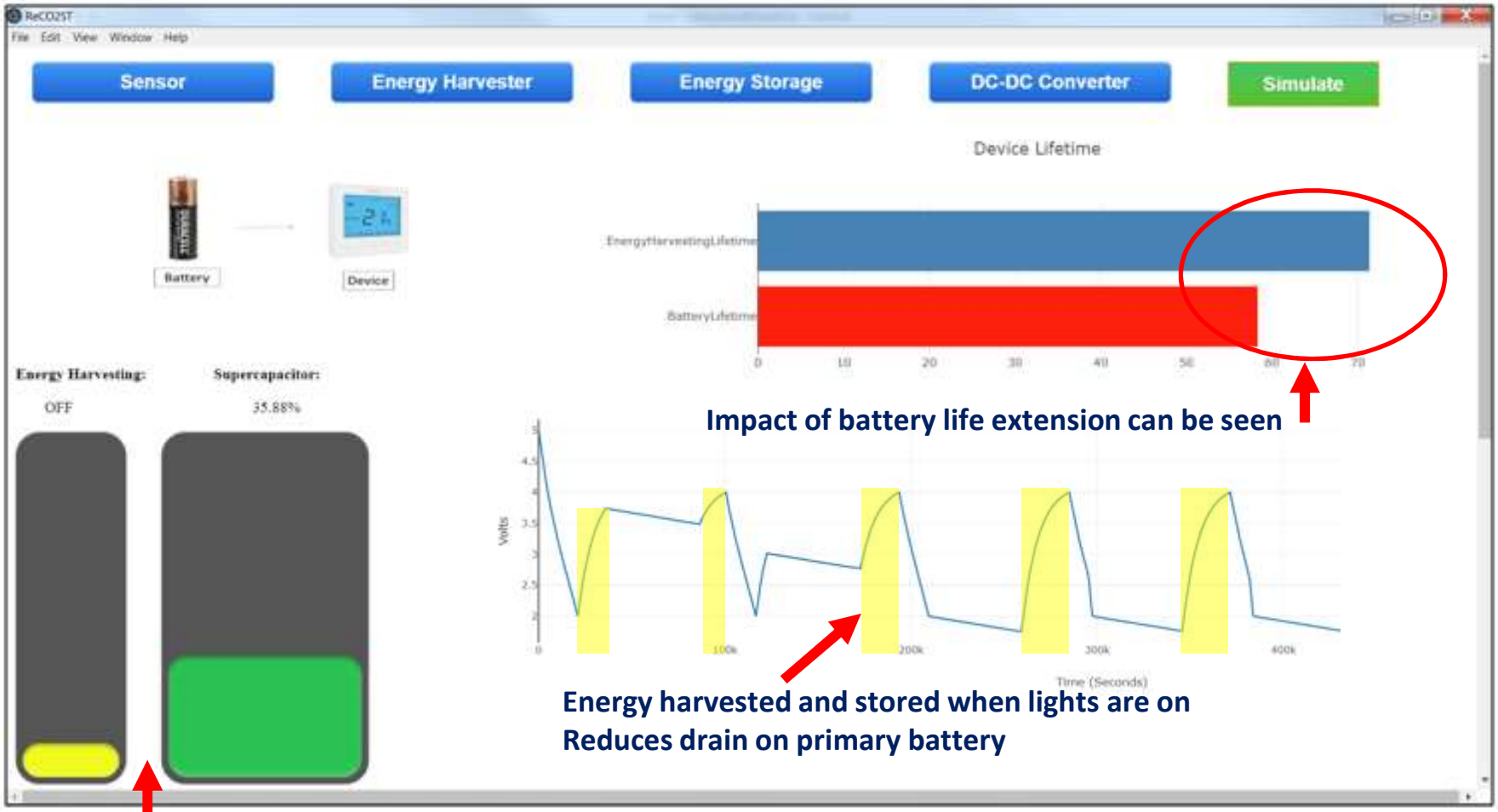


Select components to ensure charge/discharge stays above cut-off

Energy Harvesting source - Indoor light on

ReCO2ST battery life tool

Newest version of ROWBUST on EU ReCO2ST project will also give overall battery life estimate



Impact of battery life extension can be seen

Energy harvested and stored when lights are on
Reduces drain on primary battery

Dynamic visual aid to see charge and discharge on supercap when lights are on/off

Some use cases - EU FoF project

Ecosystem for COllaborative Manufacturing PrOceSses – Intra- and Interfactory Integration and AutomaTION

- Creating a digital automation framework (IIMS) that optimizes the manufacturing processes by exploiting existing data, knowledge and tools to increase productivity and dynamically adapt to changing market requirements.
- Development of middleware that enables inter-operably between systems was pivotal to the project (several of the partners are here today)
- **Tyndall role:** Supply expertise in WSN at component, device and system integration level for both modelling and real time operation of the use cases (particularly retrofit of self-powered sensors for inter-factory use cases)
- Gave us opportunities to show value add of wireless sensors with 2 use cases

Fraunhofer FIT Co-ordinator

(Grant Agreement No 723145)

Industry 4.0 Uses Case

Condition Monitoring (CM)

- **Retrofit of wireless acoustic sensors that 'listen' to the oven blowers (fans) – detection of failure.**
- **Algorithms developed to accurate calculation of risk of fan failure to weeks/months**
- **Just 5 sensors need to monitor a cluster of 32 fans**
- **Move from Scheduled to Predictive Maintenance**
- **Estimate cost of a fan failure during production is ~ €40K (material waste + downtime)**

In future projects

- **Make the sensor self powered or at least make the battery last longer**
- **Look at 'roaming' CM system applications (rather than static)**

Industry 4.0 Uses Case

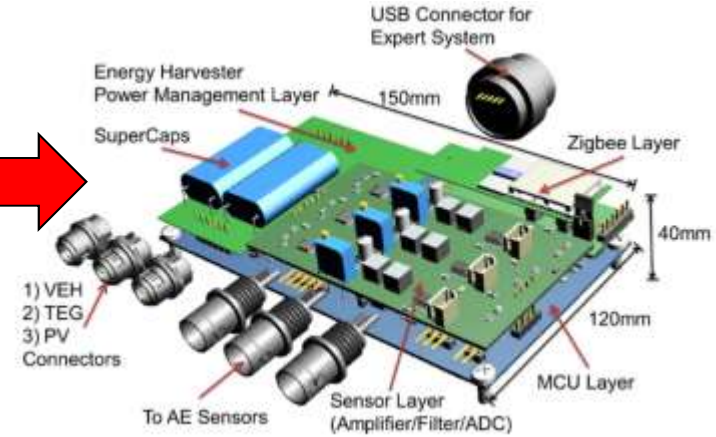
Asset Tracking

- **Ability to quickly track assets, e.g. inspection microscopes, using off the shelf sensors**
- **Tyndall expertise used to select and install hardware, feed required data to other COMPOSITION partners**
- **Retrofitted PV Energy Harvesting to Beacons that doubled battery life from 260 to 550 days**

In future projects

- **Self-power the sensors - eliminate battery maintenance**
- **Integrate emerging technologies that enable size reduction**
- **e.g. fit on trays or unobtrusively into equipment**
  - **(RF protocols, power management, sensors, batteries)**
- **Integrate emerging technologies that improve range/accuracy**

Commercial Buildings Example



Multi source harvester

Use light, vibration or heat from compressor to self-power a ‘diagnostic unit’

Does predictive maintenance on cold room compressor & food storage rooms

Industry 4.0/ Commercial Buildings Example

Indoor solar powered 'Nod'

Interactive sensor to help optimize comfort in an office/factory

60% battery life extension achieved

Could become self powered as RF and air quality sensor technologies evolve

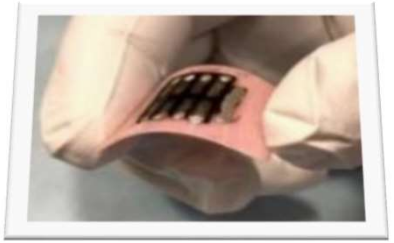
Come join our Ecosystem

EnABLES

EU Project 730957

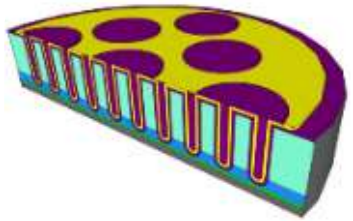
- Our Transnational Access program gives
  - Free of charge access to expertise & laboratories
  - Feasibility studies

  (paper, simulation, characterisation, proto)



Sign Up at www.enables-project.eu to follow our activities or to register an enquiry

- Joint Research Activities are creating
  - System optimised, application orientated solutions
  - De-risked & standardised methodologies & library parts

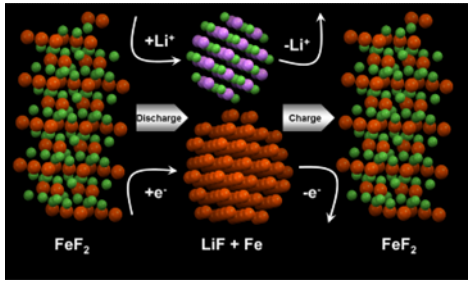


(Si embedded storage)

Check out

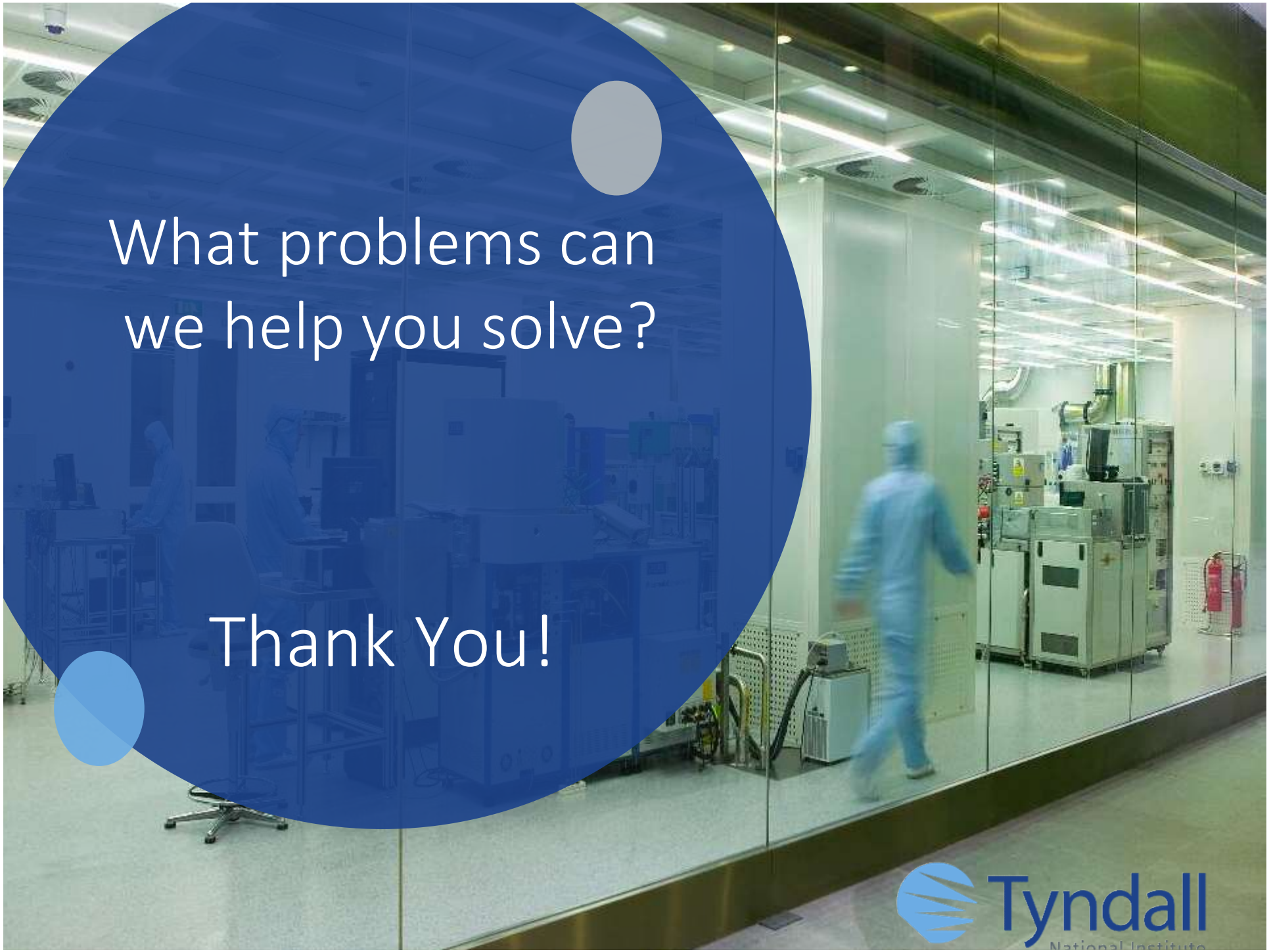
Our publications: https://www.enables-project.eu/outputs/

This also has our template for standardising parts development



(Printed batteries)

Tyndall National Institute · Fraunhofer · cea · imec · KIT · Politecnico di Torino · NiPS Laboratory Noise in Physical Systems · Alma Mater Studiorum Università di Bologna · University of Southampton


What problems can we help you solve?
Thank You!
Tyndall

Acknowledgements

- This work was sponsored by the following projects

MISCHIEF

ENTERPRISE IRELAND

RoWBUST

iERC International Energy Research Centre

ReCO2ST

EnABLES

COMPOSITION

MOEEBIUS

MOSYCOUSIS

- We would like to take this opportunity to thank the ICT4EE team at Tyndall and all our EU project partners