Energy Harvesting Committee (EHC) Minutes
13th May 2020

Attendees	Apologies/Non attendees	
John Horzepa, PSMA Scott Thielman, Product Creation Studio Sebastian Bader, MIUN Lorandt Foelkel, Wurth Peter Haigh, Tyndall Maeve Duffy, NUIG Thomas Becker, NTA- ISNY Michalis Kiziroglou, Imperial College London Francesco Carobolante, IoTissimo **Brian Zahnstecher, PowerRox** **Mike Hayes, Tyndall**	George Slama, Wurth (GUEST) Mohamed Jatlaoui, Murata Robert Andosca, AEI Steve Savulak, UTRC Johan Pederson, Sigma Design Mike Wingard, Amphenol Katherine Kim, UNIST Anthony Laviano, NRAIT Henrik Zessin, Fraunhofer IIS Justin Knott, FCI Jae-Do Park, Univ of Colorado Denver Nathan Jackson, Univ of New Mexico Warren Wambsganss, Astronics Jeffrey Jouper, Astronics Seshank Malap, Tektronix Denis Pasero, Ilika Roberto la Rosa, ST	*Doug Osterhout, Google* Wensi Wang, BJUT Peter Zou, Huawei Ajinder Singh, TI Aaron Stein, Dartmouth Kevin Parmenter, TSC Guoqing Liu, Huawei (HiSilicon) Jochen Koszescha, Infineon Laili Wang, Xi'an Jiatong University David Newell, NUIG Dan Stieler, PowerFilm Sam Jones, PowerFilm Jamil Khan, Univ of Newcastle (AUS) Dusan Vuckovic, Ikea Baoxing Chen, Analog Devices Gary Johnson, Ilika (for Denis) Joe Horzepa, PSMA Marcus Taylor, Fleximatix

(Co-chairs in bold font)

Next meeting:- Thurs 11th June, 10am CDT, Mike to chair, Brian to type.

Agenda

0. EH COMM PURPOSE STATEMENT REVIEW
1. Welcome any new members/guests.
2. EnerHarv 2020 planning.
3. APEC 2020 closure
4. Industry Event Watch
5. Webinars
6. White paper.
7. 'Treasure Chest' at end of the minutes.
- **7A. Student Competition**
- **7B. Updated Goals**
- **7C. Forward-looking Thoughts**

0. Committee Purpose Statement

(REVISIT AROUND AUG TIMEFRAME)

"***The purpose of the energy harvesting forum is to collect and disseminate information related to energy harvesting. The committee's mission is:***
To support the mission, vision, goals and objectives of PSMA by developing an ecosystem that provides subject matter expertise & direction on the adoption & integration of energy harvesting and related energy storage, conversion and low power technologies; demonstrating that collaboratively we can truly accelerate the adoption of IoT in commercially feasible consumer, industrial applications and beyond."

1. Welcome New Members

None so far

2. EnerHarv 2020

- ***NCSU – North Carolina State*** **DEFERRED, NOTICE SENT 3/13/20, NEW DATE TBA**
  - **Brian to talk with Steve Savulak and close out financials**

3. APEC 2020 Closure

Decided not to go virtual. All proceedings etc. available on line for download.
Can any of the intended material be converted to a webinar candidate? Ref section 6.

4. Industry Event Watch

- Revisit/update the list of good industry events for tracking.
- Francesco recommends www.iwpc.org as resource.
- As a support document Mike has modified EnABLES event sheet and circulated 22nd April. He will update and circulate every quarter – next one due July
- Any volunteer to champion creating this? Scott considering, keep it light, for now review and augment, circulate to the EHC, people are free to forward on, all public domain info.
- ALL – any inputs for the list??? Check monthly.

5. Webinars

- Mike & Peter Haigh will give industry 4.0 powering retrofit WSNs webinar 28th May.
- John to send flyer/banner to Mike & Brian, add to minutes
- ANY OTHER VOLUNTEERS? It is OK to re-cycle an old presentation.
- There will be an EnABLES power mgt webinar 16th June, presented by Fraunhofer, Tyndall and UNIBO - details can be found here http://www.enables-project.eu/webinars/
- Old webinar suggestions (in italics) – we need everyone to review this and give us updates
    - *Dan Stieler, PowerFilm was considering one (will be chased by way of Sam)*
        - *Sample abstract suggested per existing blog (https://www.powerfilmsolar.com/about-us/the-horizon-blog/2018/08/10/outdoor-vs-indoor-solar-the-key-differences),*
    - *Lorandt willing to do 1 back n 2019*
    - *Dusan was thinking about an applications orientated presentation*
    - *Brian and Raj (GeorgiaTech) gave IEEE EPS webinar on IoT with Dushan, Marc & Denis - Can do a variant for PSMA?*
    - *Would be good to do 1-2 on 'practical real life performance' of parts and systems – comparison of technologies. Saw some good examples at EnerHarv e.g. Ilika & ARM presentations*

6. White paper

- Michalis Kiziroglou & Thomas Becker leading this initiative, latest strawman was reviewed at the May meeting and on the next 4 pages.
- Maeve and Mike willing to be contribute – any other volunteers from EHC to be contributors, please let Thomas, Michalis, Brian and Mike know.
- MK/TB will propose schedule and key actions (5-6 lines),

White Paper
Energy Harvesting for a Green Internet of Things

Executive Summary

Responsible/Contributor: Brian, Mike…?
Introduction from PSMA EHC perspective

Abstract

- *Objectives of the white paper*
  + *To identify challenges and opportunities in adopting energy harvesting as a method to ensure an environment-friendly Internet of Things.*
  + …
- *Guide through the white paper,*
- *Classification against renewable energy etc.*

Content

1. State-of-The-Art from the Perspective of the User (Responsible: ../Contributor: Michalis …)
1.1 Motion, Thermal, Inductive, RF, Solar, Acoustic
1.2 Broadband functionality (environmental range, multiple functionality)
1.3 Power Management and Storage

- **THIS SECTION SHOULD EXPLAIN WHAT 'WE' AS ACADEMIC PARTNER (UNI, RES) WANT TO DO IN TERMS OF R&T**
- **& WHY FUNDING IS NEEDED ON NATIONAL/LOCAL, EU, US… LEVEL**

2. Developing for a Use Case (Responsible: Michalis /Contributor: …)
2.1 Specifications. A loop of size and power.
2.2 Energy and Power Budgeting
2.3 Ultra-Low Power Consumers

- **THIS SECTION SHOULD EXPLAIN WHY 'WE' AS ACADEMIC AND INDUSTRIAL PARTNER WANT TO WORK TOGETHER IN TERMS OF R&D**
- **& WHY FUNDING IS NEEDED ON NATIONAL/LOCAL, EU, US… LEVEL**

3. Key Missing Elements for Industrial Adoption (Responsible: Thomas /Contributor: Eric …)
3.1 Operational
3.2 Economical
3.3 Standards

- **THIS SECTION SHOULD EXPLAIN WHY 'WE' AS ACADEMIC AND INDUSTRIAL PARTNER WANT TO WORK TOGETHER IN TERMS OF R&I**
- **& WHY FUNDING IS NEEDED ON NATIONAL/LOCAL, EU, US… LEVEL**

4. Key Advantages (Responsible: …. /Contributor: …)
4.1 Cost benefit
4.2 Reliability
4.3 Environment and sustainability

- **THIS SECTION SHOULD EXPLAIN WHY 'WE' AS ACADEMIC AND INDUSTRIAL PARTNER WANT TO WORK TOGETHER IN TERMS OF R&T&I**
- **& WHY FUNDING IS NEEDED ON NATIONAL/LOCAL, EU, US… LEVEL**

5. Opportunities (Responsible: Eric /Contributor: Thomas …)
5.1 New Ideas
5.2 Green Impact
5.3 Funding Modes

- **THIS SECTION SHOULD EXPLAIN HOW COMMON R&T&D&I EFFORTS SUPPORT NATIONAL/LOCAL, EU, US OBJECTIVES ON CLIMATE, INNOVATION, LEADERSHIP…**
- **AND WHY THEY SHOULD GIVE US MONEY ☺**

1. State-of-The-Art from the Perspective of the User

This section reviews the methods and summarises the related technologies for energy harvesting systems. The focus of the review is to demonstrate the technical excellence of energy harvester devices, to illustrate the technical implementation into IoT devices and to analyse the technical limitations in autonomous wireless sensor and actuator networks. The state-of-the-art analyses provides the background for the economic and ecological assessment of energy harvesting systems. Opportunities derived from cost benefit analyses and life cycle assessments are depicted in the next section.

- Energy harvesting (EH) is an umbrella term to describe methods for converting ambient energy sources into electrical energy in the context of wireless sensor networks (WSN) or the internet of things (IoT)!
- Power management and energy storage are integral parts of an energy harvesting device!

1.1 Motion, Thermal, Inductive, RF, Solar, Acoustic
Michalis…

1.2 Broadband functionality (environmental range, multiple functionality)

1.3 Power Management and Storage
Impedance Matching, rectification and sub-threshold switches, buck/boost, inductor integration, key storage issues - resistance limitations, circuit/storage co-design, cold-starting.

2. Developing for a Use Case

2.1 Specifications. A loop of size and power.

- A detailed analysis of the application is necessary for selecting the suitable energy harvesting technology!
- Adequate measures to balance energy and power demands from the application with the energy and power provision capabilities of the harvesters are essential!

2.2 Energy and Power Budgeting
- Energy balance harvester vs consumer (budgeting of power and energy, graph of duty cycle vs size?)

2.3 Ultra-Low Power Consumers
Passive sensors
Multilayer sleep modes
Multilayer duty cycling: sensing, processing, storing, transmitting.

3. Key Missing Elements for Industrial Adoption

- Technological end-users perspectives may differ dramatically from technology provider point of view, since the total system performance requirements are essential!
- Commercial end-user expectations are clearly focussed on the overall efficiency enhancement instead of isolated technological improvements!

Energy harvesting offers many advantages compared to batteries or wires as described in the previous chapters. However, for a successful implementation in future applications several acceptance limitations have to be solved. Key challenges are listed below:

- System integrators are used to specify the technical behaviour of devices as a black box with defined interfaces for input and output parameters. In case of energy harvesting devices detailed information about the installation environment is required from the supplier. Even though system integrators and Tier-X suppliers are working today in closed-loop development frames the exchange of data is critical. For example the data of vibration frequencies and amplitudes of a car or an aircraft may exhibit design compromises in terms of noise or comfort.

- Durable assets, such as cars, machinery or aircraft, require a certain MTBF (meantime between failures) guaranteed. Moreover, the consequences for the subsystem, where the energy harvesting device might be integrated, have to be considered in case the expected lifetime cannot be achieved. As a consequence, the user's confidence in the product is fading away.

- In most cases, energy storage is required additionally to the energy harvester device itself. In general, batteries or supercaps are often seen as potential hazard source because of the high energy density. In any case, due to the electro-chemical nature of storage devices limitations in lifetime and therefore maintenance costs are expected.

- Adequate energy supply in the situation of non-standard operation (repair…) of the system is a key challenge for energy harvesting. The energy harvesting devices are designed to cope with a broad spectrum of in-service operations. However, during MRO (maintenance, repair and overhaul), longer downtime or other unexpected events the energy harvester might not supply energy and the energy storage might be drained. Changing procedures for MRO or restarting the system is costly and unlikely.

- Materials aspects and recycling are likely to generate additional costs. Energy harvesting devices may contain substances hardly to recycle although complying with RoHS, ReEACH obligations.

- Obsolescence management is another key challenge. In the split and dynamic emerging market of energy harvesting devices the provision of spare parts is a critical issue. Due lack of standards and many start-ups a possible long term supply chain remains unclear.

3.1 Operational
3.2 Economical
3.3 Standards

All the above mentioned aspects need be carefully analysed in a detailed CBA (cost-benefit-analysis). Moreover, the CBA needs to be substantially supported by cradle to grave life cycle assessment (LCA). In addition, standardisation efforts should be made to pave the way for using energy harvesting devices.

4. Key Advantages

This section describes opportunities with regard to economic and ecological excellence of autonomous wireless sensor and actuator networks. The expected benefits clearly underpin the demand of further R&D&I efforts towards a sustainable green transition of the internet-of-things supporting world-wide Green-Deal measures.

4.1 Cost benefit

- Positive cost-benefit-analyses (CBA) may result in implementing energy harvesters into systems in order to reduce personnel, maintenance or in-service costs!

- Rethinking the touchstone application with 'infinite power' might by inevitable to achieve positive CBA results!

- Could costs be saved by EH?
- Cost Benefit Analysis, Comparison to wires, batteries,
- Reconsideration of the Application Scenario/Virtual Sensing

4.2 Reliability

4.3 Environment and sustainability

- Environmental benefits may not turn to account today but in future due to changing regulations!
- Products with positive life cycle assessment (LCA) may reach higher consumer acceptance at higher prices!

- Are there other good reasons to use EH?
- Life Cycle Assessment, GWP, CO2eq, SO2eq

5. Opportunities

5.1 New Ideas

- Massive IoT may lead to less complex but denser measurement strategies enabling autonomous virtual sensing!
- Standardisation efforts are desperately required to enable wider commercial deployment of energy harvesters!

- Future Harvesting Research Needs
- Standardisation (current situation, suitable organisation)

5.2 Green Impact

- Autonomous virtual sensing requires will a complex ecosystem with many stakeholders and needs support and guidance in research agendas worldwide!
- Standardisation efforts on component level have to be support in concerted actions to reach standards on subsystem level!

5.3 Funding Modes

- Why we should go ahead with EH?
- Expectations to funding bodies, EU, US, China…!

Key Requirements for Profitable Public Investment
Key Requirements for Profitable Private Investment
Profitable investment: Energy harvesting as a combination of

Environment-friendly approach
Recyclable materials
Operational sustainability for industry, transportation and infrastructure
Minimized operational cost in economical, environmental and complexity terms.

1. References

maybe in the footer of each section?

About PSMA and EHC

Responsible/Contributor: Brian, Mike…?

END OF WHITE PAPER

TREASURE CHEST

Approach these items one at a time in future meetings as people raise them.

7A. Sponsorship of a program where students build demonstrators.

- Lorandt has a budget to supply kits
- Help with education links – Qualcomm 'High Tech High'. Francesco will follow up.
- Green story. International dimension. Technology and applications dimensions.
- Wurth running design challenge.
- Keep simple, easy to use
- Competition or roadshow?
- PSMA has money to support.
- Action:- Catherine and Mike met at EnerHarv & discussed, She will write ½ page strawman for student engagement mechanism. Mike will ping again. **NEED A CHAMPION TO LEAD EFFORT FOR COMM** **Maeve willing to help but does not have bandwidth to lead.**

"Here are Katherine's thoughts on the competition:

There are two main styles of the competition that could be developed:

1. Engineering-Style Competition

- planning committee chooses specific EH devices that can be used and the target load
- planning committee also specifies energy input conditions (lighting setup, vibrational input, etc) for testing
- specifications are announced and teams would develop the power converter solution based on the specification
- teams can submit videos and/or reports on their team and proposed idea
- final teams are selected and they test their prototypes on site at an event competition (could be a conference)
- judging is based on technical criteria measured during the test (size, weight, efficiency, etc.)
- implementation is the most important aspect for this style of competition
- over different years, the specification and scenarios would focus on different technologies with the same basic format
- more similar to the International Future Energy Challenge run by PELS

2. Design-Style Competition

- planning committee could choose a theme based on a technology or application (e.g. smart homes, wearables, building monitoring, etc.)
- planning committee may want to specify some constraints or scenarios for the competition
- teams come up with complete EH design ideas (transducers, circuitry, load) and develop a prototype
- teams can submit videos and/or reports on their team and proposed idea
- final teams are selected and they present and demonstrate their prototypes on site at an event competition (could be a conference)
- judging is based on mostly qualitative and some quantitative judging criteria (so balanced judge selection will be important)
- this style of competition is more focused on the idea and design, but implementation is also important

There should probably be some discussion on which style the committee would like to see. The engineering-style requires a lot of prep work before even announcing the competition, while the design-style is more work for the judging and evaluation. I could see either being good for students. I hope someone can take these basics ideas and further development them into a competition."

7B. Updated Goals

- Open to suggestions.
- We should try to forge links with other groups/sessions, e.g. capacitor, magnetics, packaging. – addressing this via "Tiger Team" effort within PSMA (multiple focused initiatives with small teams from various committees)
- **BZ INITIATIVE**: working on feasibility for an official, IEEE Future Directions initiative on Energy Harvesting (a 1-6yr process)
    - JOE notes PSMA would be happy to support such an initiative, **BZ to figure out if/how**
    - BZ has obtained process detail (https://cmte.ieee.org/futuredirections/fd-opportunities/), **BZ to pitch initial proposal to PELS TC6 at ECCE on 10/1/19…WILL SHARE FINAL PPT WITH TEAM**

7C. Forward-looking Thoughts

- Software? Packaging/industrial design? Modelling?

Mike Hayes & Brian Zahnstecher,
13th May 2020.