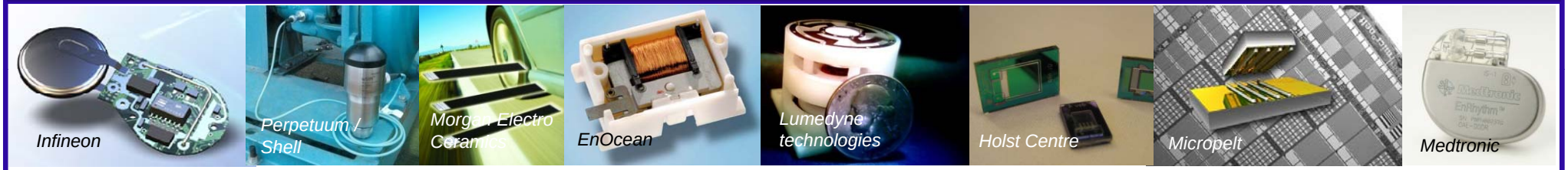
MEMS Energy Harvesting Devices, Technologies and Markets, 2009

Market drivers analysis for challenges that go beyond energy density!

SAMPLE Version – February 2009



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Conclusion

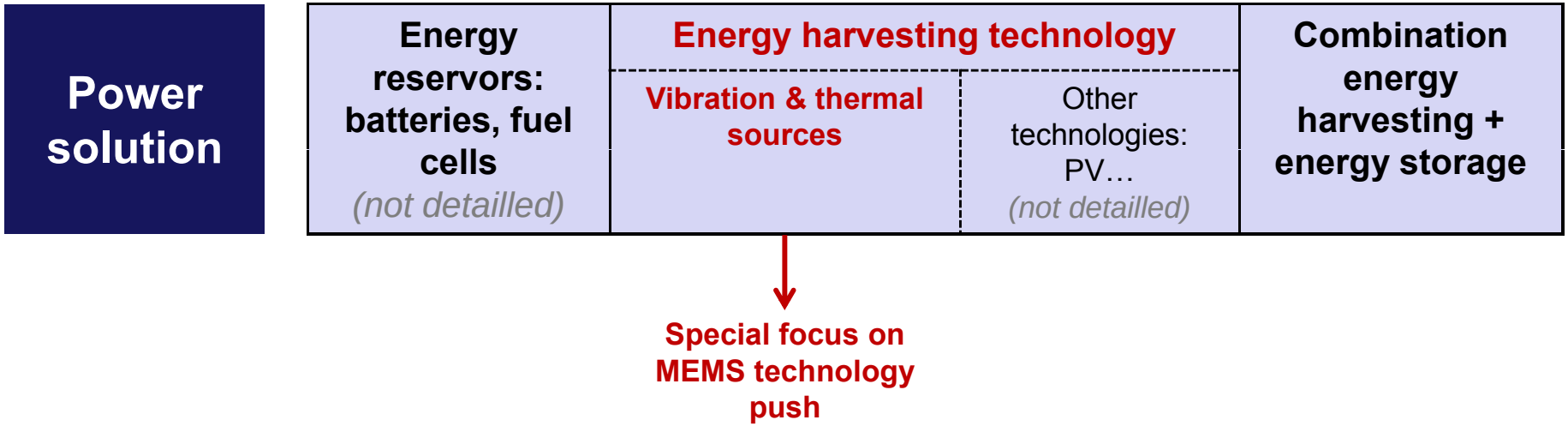
Company profiles

Energy harvesting: main players and status

- A. AdaptivEnergy
- B. EnOcean
- C. Holst Centre
- D. Lumedyne Technologies
- E. MEMS@MIT
- F. Micropelt
- G. Microstrain
- H. Morgan Electro Ceramics
- I. Piezo TAG
- J. PMG Perpetuum
- K. Thermo Life
- L. TPL Micropower
- M. Transense Technology
- N. Visityre

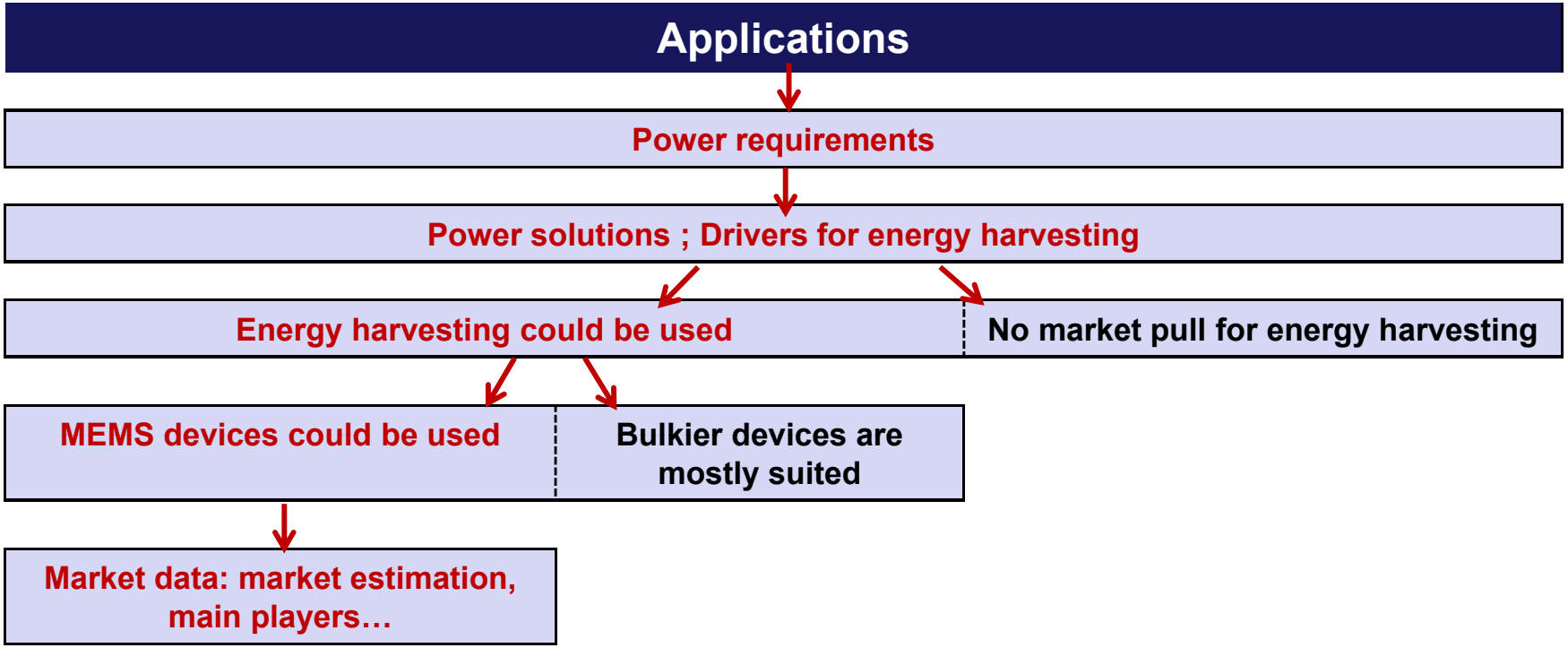
Scope of the report

- **This report is divided in three major parts:**
  1. **Technology description:**



Scope of the report

2. Screening of applications:



3. Company profiles:

Company profiles		
Players who develop MEMS devices for energy harvesting	Most active R&D centers and companies in vibration & thermal energy harvesting	Other companies *(not detailled)*

Executive Summary

- **In an environmentally conscious world, MEMS Energy harvesting devices promise a cleaner and almost perpetual solution to powering small systems, without the use and waste of polluting batteries**
- **But energy harvesting systems require significant advances before going to the industrialization stage**
  - Need for better power density
  - Ultra low power electronics
  - Small energy storage devices with high energy capacity
  - Wireless communication standards & transmission rate improvements
- **Energy harvesting still faces technological challenges**
  - Electromagnetic or electrostatic systems: only produce tiny amounts of energy in tiny sizes
  - Piezoelectric films: difficult to deposit
  - Thermal systems: often inefficient and costly
- **However, notable advances have been reported in the previous years**
  - At the macro scale, several mW of power can be obtained with electromagnetic technologies by harvesting vibrations from industrial environments
  - According to the latest developments, piezoelectric MEMS energy harvesting devices can currently power sensor nodes requiring 60 µW
  - Improvements in energy storage devices are also significant
    - Today, there are more than 10 companies working in the microbattery area
    - Microbatteries with capacity up to 50 µAh are already in production

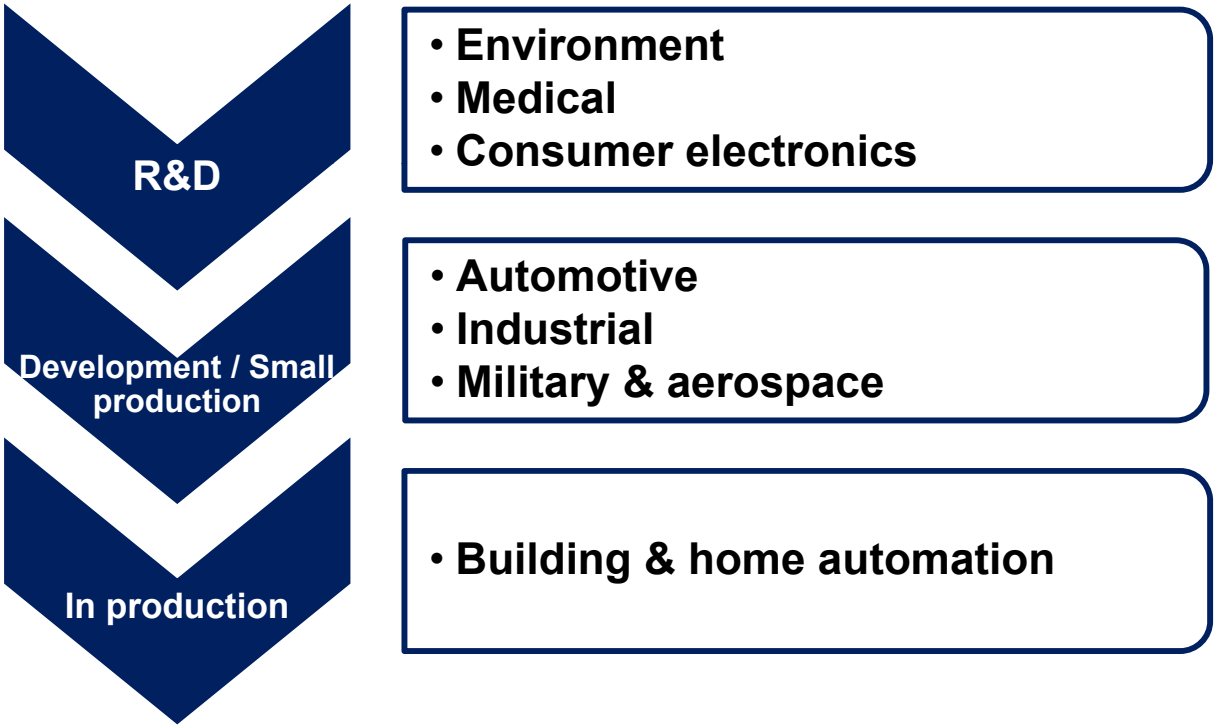
Executive Summary

- **But energy harvesting is still R&D driven**
  - There is still no high volume application for energy harvesting systems
    - Using batteries is still the preferred solution for powering small devices
  - Market acceptance of MEMS energy harvesting devices is very application-dependant
    - This is a function of several parameters:
      - Size & weight
      - Amount of power generated versus amount of power needed by the system
      - Cost: Ease of access to grid & Ease of access to the module or system to power
      - Number of devices to power
      - Critical mission of the module or system to power
      - Required device lifetime: Projected lifetime for the energy harvesting device compared to the system parts lifetime
    - A major factor to be taken into account is if there is enough power harvested for a particular application from a particular environment, and if the scavenged power needs to be stored
- **Commercial applications are slowly starting to go to market**
  - First sales of energy harvesting applications are not necessarily at the micro scale
  - Hottest market segments are:
    - Industrial applications: machine condition monitoring
    - Building & home automation
    - Tire Pressure Monitoring Systems, where batteries are currently the dominant solution, has driven enormous efforts but the market dynamics have not made it possible to accept a premium price for alternative solutions
  - But no killer application is foreseen for the coming years
    - Market push could come from chip thermal management, in a “more than moore” vision

Overview
Energy harvesting technologies status

- **Outside of the building & home automation field, production of energy harvesting systems is still insignificant today**
  - 8 application fields are concerned by energy harvesting developments
  - For the majority of screened applications, no significant production is expected in the next 2 or 3 years

Status of energy harvesting devices* in the different application fields, 2009



** Only vibration and thin film thermal energy harvesting technologies are considered; Photovoltaic is not taken into account*

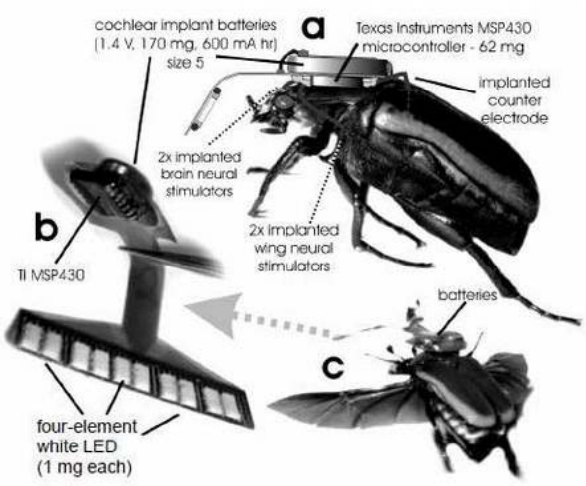
Example of application: military and aerospace field

Military Field
Field overview

- **The main applications of energy harvesting in the defense field today is in aircrafts and helicopters:**
  - **The vibration of the helicopter structure can be used to power low-power wireless electronic systems used in the HUMS modules**
    - **This application is described in the following slides**
  - **Various other potential applications are in R&D stage:**
    - **Battlefield surveillance with wireless sensor networks: battlefield surveillance, sensing intruders on bases, detection of enemy unit movements, chemical/biological threats**
    - **To power sensors on hybrid insects**

      A DARPA program concerns power MEMS designed to harvest vibration energy from the movement of wings. The main driver of this program is to eliminate the size and weight issues caused by the battery
    - **DARPA is also working on micropower generation (based on mechanical actuation and thermal-electric power generation) and on radioisotope micro-power source.**

      The use will be for portable and mobile applications which require relatively low average power (mW to few hundred milliwatts): munitions, unattended sensors and weapon systems, various remote, field deployed microsensors and microactuators....



DARPA

	Power needed	Category of power solution	Power source technology	Trends
HUMS	250 µW	Grid	Hardwired: use helicopter main power	Large production
		Energy harvesting	Electromagnetic energy harvesting	Small production
		Energy harvesting	Piezo energy harvesting	Very small production

Application
Health and Usage Monitoring Systems (HUMS)

- **Health and Usage Monitoring Systems (HUMS) contain sensors for monitoring the external state of helicopters or rotary wing aircrafts**
  - **Objective: critical component diagnosis and prognosis (with accelerometers…) + environment sensing (temperature reading…)**
  - **This is an emerging application for both civil and military markets**

    HUMS systems will be generalized in 2010

    Micro versions of HUMS are also being developed: for UAV applications

RSL Electronics

HUMS
Power solutions

- **Conventional HUMS systems require sensors to be wired**
  - Drawback: such systems are expensive to install
  - Wireless sensors with radio-transmission of the data are emerging
- **Vibration energy caused by the rotation of the rotor can be harvested**
  - This vibration is present throughout the body of the aircraft: sensors powered by this vibration energy can thus be placed anywhere in the aircraft structure.
  - Frequency depends on the speed of the rotor and the number of blades

    Usually between 10 and 25Hz
  - Typical strain level: 35 microstrain at 5Hz
  - Typical frequency of transmission needed: several kbytes of data every few minutes, or smaller amounts of data several times a second

HUMS
Main players

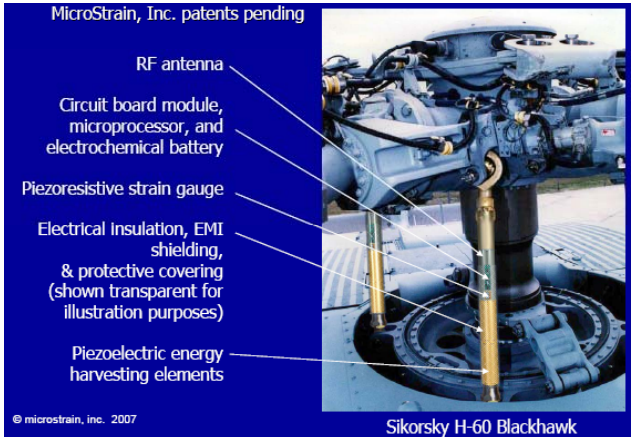
- **Electromagnetic technology (macro scale):**
  - **Perpetuum PMG17: optimized for 17.2Hz vibrations**
    2mW obtained with 25mg vibration magnitude
  - **Lumedyne Technologies (development stage)**

Perpetuum

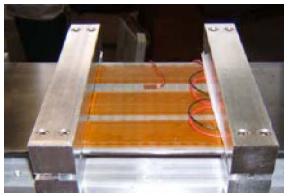
- **Piezoelectric technology (macro scale):**
  - **Microstain (PZT from Smart Materials)**
    Details can be found on the following slide

HUMS
Main players

- **Ex of player: Microstrain**
  - **Energy harvesting wireless pitch link has been successfully tested by Microstrain on a Bell Model 412, in 2007**



  - **Piezoelectric vibration energy harvesting is used:**
    - **12 PZT patches are used**
    - **Each has dimensions of 3'' x 1''**

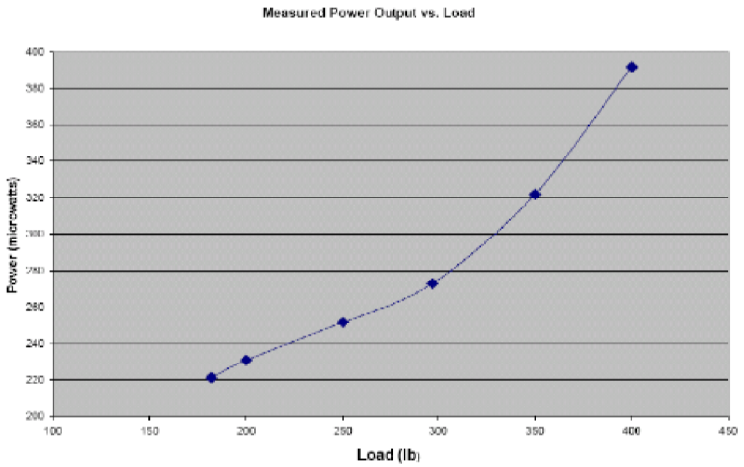


  - **The power consumption for this module is relatively low:**
    - **Sensing part:**

    For one measurement per second: 3.2 µW

    32 samples/sec => power consumption

    102 µW (34 µA at 3V DC)
    - **With wireless transmission: 250 µW**



Source: Microstrain

HUMS
Main players- supply chain