



FEONIC POWERCELL SENSOR

Compact, low cost, quick to install
autonomous, remote conditional
monitoring for industrial
and rail applications

INFORMATION MEMORANDUM

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Feonic Vibration Technology

Autonomous Wireless Sensors Powered from Vibration

Feonic Powercell Sensor

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1 Executive Summary

1.1 Vision

The Feonic® power module generates electrical power from the natural vibration of machinery and equipment.

Patented worldwide, Feonic smart-material generators are used to power sensors and wirelessly deliver real-time conditional data to the Cloud without batteries, wiring or any additional support infrastructure, even in the most hostile environments for any manner of industries.

"Our aim is to lead the market for autonomous sensors through exploiting our patented world-class power generating technology specifically providing sustainable energy to millions of sensors that form The Internet of Things (IoT). We will lead the market where autonomous conditional monitoring is critical in volatile, violent, extreme and destructive environments"

The Feonic Vibration technology is enabling a 'game changer' in the design of cheaper, lighter and smaller rugged autonomous wireless sensors.

1.2 Market Need

There is a requirement across many industries for a self-contained, autonomous, and maintenance free sensor to monitor the condition of critical assets.

Regularly monitoring the condition of an asset enables a move away from time-based maintenance regimes to condition based maintenance thus extending the periodicity of the maintenance and lowering the costs.

In addition, regular monitoring in between service intervals reduces the risk of between service failures and catastrophic failures. Catastrophic failures of rail wheel bearings have caused major accidents on rail networks

- **The projected market for autonomous wireless sensors is \$5b by 2020** (Mordor Intelligence) at a CAGR of 6.7% (MarketsandMarkets Analysis)
- The growth of the market is driven by the development of a **secure cloud computing platform**, increased use of **wireless communication** technology and **inclination of end users towards predictive maintenance**
- Predictive maintenance using prognostics requires data- sensors provide the data
- The Internet of Things is driving the need for cost effective data to reduce maintenance costs and improve reliability
- Battery powered sensors have a limited life and are expensive to maintain
- Sensors that require external power require cabling which can be very expensive. The high cost of cabling kills the business case

At present most spend is on hardware rather than software & hardware will account for most growth in the coming years. **The market is demanding cost effective, maintenance free, and reliable, self-powered wireless sensors with Vibration monitoring technique to hold the largest size of machine conditional monitoring market between 2018 & 2024** (MarketsandMarkets Analysis).

1.3 Market Opportunity

The market opportunity is the monitoring of critical assets that vibrate using energy harvesting.



Basic Energy Harvester
Power Module
65mmx 17mm x17mm
plus mounting flanges



Power Module with Storage
Hybrid Powercell
85mmx 17mm x17mm
plus mounting flanges



Power Module, Sense & Send
Hybrid Powercell Sensor
118mm x 36mm x 33mm



**Autonomous monitoring of assets
that vibrate, using energy harvesting**

The assets can be anything from industrial motors, gearboxes, rail wheel bearings, rail traction motors to escalators and lifts.

Additional applications include the following:

- Monitoring of rail track condition using sensors mounted within rail rolling stock.
- Applications where cabling to sensors is too expensive or too disruptive.
- Applications where the cost of changing a battery is too expensive or the cost of locating an asset with a failed battery is prohibitive.

2 Rail

Monitoring the integrity of rolling stock axle bearings, traction motor bearings, gearbox bearings and turbocharger bearings provides a total global bearing installed opportunity of an estimated 40+ million units.

The market opportunity within the legacy rail rolling stock sector is based on a global fleet size of 5.6m vehicles.

Global Rail Market - bearings	Global fleet size- units	Assumptions	Fleet size - vehicles
Electric locos	47,000		47,000
Diesel locos	92,000		92,000
EMU's	40,000	Assume 5 vehicles per unit	200,000
DMU's	15,000	Assume 5 vehicles per unit	75,000
LRV's	31,000	Assume 5 vehicles per unit	115,000
Metros	N/A		
Passenger cars	60,000	Assume 5 vehicles per unit	300,000
Freight wagons	4,800,000		4,800,000
Total	5,085,000		5,629,000

Fleet Size - Global Rail Market 2015 - UIC

Bearings/vehicle	Axle	Traction	Turbo	Gearbox
Electric locos	8	4		
Diesel locos	8	4	1	4
EMU's	8	1		
DMU's	8		1	1
LRV's	8	1		
Metros	8			
Passenger cars	8			
Freight wagons	6			

Assumption of bearings per vehicle per system

Note: The above figures are a conservative estimate of the number of bearings per vehicle. As an example, a significant percentage of the freight wagons have 8 bearings per vehicle rather than the indicated 4.

Global Rail Market - bearings	Global fleet size- units	Fleet size - vehicles	Axle bearings	Traction bearings	Turbo bearings	Gearbox bearings	Total Global Fleet Size
Electric locos	47,000	47,000	376,000	188,000	0	0	
Diesel locos	92,000	92,000	736,000	368,000	92,000	368,000	
EMU's	40,000	200,000	1,600,000	200,000	0	0	
DMU's	15,000	75,000	600,000	0	75,000	75,000	
LRV's	31,000	115,000	920,000	115,000	0	0	
Metros	N/A		0	0	0	0	
Passenger cars	60,000	300,000	2,400,000	0	0	0	
Freight wagons	4,800,000	4,800,000	28,800,000	0	0	0	
	5,085,000	5,629,000	35,432,000	871,000	167,000	443,000	36,913,000

Global Market for Rail Bearing Monitoring

An additional application is the use of the rolling stock to monitor the condition of the rail track. The sensors installed on axle boxes would be used for this purpose.

2.1 Who are the Customers in Rail?

There is a trend in the rail industry that train builders are supplying new trains with an ongoing maintenance contract including the provision of staff and depots.

The contracts tend to be long term based on a combination of availability, duration and mileage with penalties for lack of availability.

However, the legacy fleets which represent over 80% of the global fleets are maintained by a combination of in-house maintenance teams, specialist contractors and train builders, on shorter term contracts. The mix differs between country and the age of the fleet.

Train builders have a significant disadvantage dealing with the maintenance of mixed fleets.

There is a however a common theme running through all the companies responsible for maintenance whether they be train builders or independent maintenance companies.

- Reduced maintenance costs drive increased profits.
- Predictive maintenance and the use of prognostics is one of the key tools to enable the move away from time/distance-based maintenance to condition based maintenance resulting in lower costs
- Data is required to drive the above

The focus for Feonic Vibration is the legacy fleets around the world with an understanding that new trains may be equipped with intelligent bearings.

2.2 Recent Activity in Rail

There is activity in remote monitoring of rail assets in every country and with many of the fleets. Below is a selection indicating that the market opportunity is wider than just the train builders.

- **GE**

GE has made a \$3b investment into their data business and has launched their prognostics platform Smart Signal supported by their web solution Predix.

A new division has been established to exploit the use of prognostics across both their existing fleets of 15,000+ locos but also 3rd party trains and locos around the world.

GE has identified that significant cost savings can be gained from their loco maintenance contracts by capturing data from items such as traction motors, of which there up to 6 per loco, axles and turbochargers.

GE has specified their requirement for a sensor having trialled units from Perpetuum.

- Under £200
- Access to the raw data
- Compact size enabling mounting on the outside of the axle box
- No moving parts
- Prefer to purchase rather than a managed service

Feonic complies with all the above.

- **D Bahn**

DB are fully committed to remote monitoring of both their rolling stock and their infrastructure assets working with companies such as GE and Splunk on the data analytics across multiple train types.

A current project is the remote monitoring of 300 EMD locos by GE, seen as a step along the way to extend the monitoring to all 4,000 locos.

The monitoring of axle and traction motor bearings is on the 'wish list' when a suitable solution is identified.

The initiative is being driven by DB and is not dependent on the train builders.

- **Trenitalia**

Trenitalia and SAP have announced '*Trenitalia's Dynamic Maintenance Results in Massive Increases in Reliability And Savings*' <https://industrial-iot.com/2016/09/trenitalias-dynamic-maintenance-results-massive-increases-reliability-savings/>

Another indication of how data is valued and the drive is from the train operator.

- **Amsted/IONX**

Amsted Rail is the largest manufacturer of rail freight cars in the world. Amsted has a JV with IONX who provide an end to end remote monitoring solution for freight cars including the monitoring of bearings. IONX also has a partnership with GE.

IONX currently use batteries which have a limited life. They have an ambition to replace the battery and/or adding a charging device to extend the life of the sensor to more than 15 years.

IONX are technology experts in energy harvesting and have researched the market extensively for a suitable technology and has identified Feonic as the most suitable, subject to trials and terms.

- **TFL Transport for London**

TFL have an ongoing Predict and Prevent strategy for the maintenance of their assets comprising 600 train sets, 430 escalators and 184 lifts plus additional assets.

<http://content.tfl.gov.uk/lu-asset-management-strategy.pdf>

The TFL Asset Management Goals.

- *Having the right information on our assets at our disposal.*
- *Utilising technology where we can to detect faults before they occur.*
- *Persistent attention to detail, focused on minimising root causes of failures.*
- *Maintaining assets based on criticality/ need - this removes the potential for human error from unnecessary and costly time interval maintenance.*

The TFL stated approach below highlights both the need for data and the fact that TFL is driving the initiative and are not reliant on the train builders where they are providing maintenance.

- *Adopt a 'predict and prevent' asset stewardship approach; as signaling systems are upgraded to transmission/communication-based systems, in built diagnostic and condition monitoring will improve fault detection and maintenance response, and may provide some self or remote restoration revolutionising the approach to maintenance.*
- *Transfer fleet maintenance from a service hours approach to a condition and usage basis to focus interventions on criticality, exploiting our knowledge of the assets with remote condition monitoring technology integrated with our maintenance management system whilst exploiting the use of hand held devices.*

Dockland Light Railway, part of TFL, requested a trial by Feonic to monitor traction bearings. The trial was conducted by Perpetuum due to Feonic not having a product at the time.

- **US Locos**

Amtrak maintain the majority of their fleet of rail cars and locos. Amtrak has installed a remote monitoring initiative on their loco fleet using a Witronix solution, as used on over 6,000 locos in North America indicating the acceptance of independent remote monitoring. The train owner/maintainers want a degree of independence from the train builder

- **Train Builders**

All the train builders are increasing and extending their activity in remote monitoring with the aim of reducing costs of maintenance. The monitoring of bearings is a focus and there is general interest in the Feonic product.

Siemens has taken an alternative route for bearing monitoring where they maintain a complete fleet, they have developed an audio sensor system that listens to bearing

noise as the train goes through a gate on the approach to a depot. The University of Birmingham are developing a similar system and are working with Hitachi.

- **ROSCO's** the train owners in the UK
Angel Trains, Porterbrook and Eversholt share the vision of remote monitoring of their assets and are funding installations. They are all seeking an alternative to Perpetuum. Eversholt has recently funded a Perpetuum installation.
Andy Course, chief operating officer of Eversholt Rail, added that wheelset and bogie condition monitoring is part of an ever larger Eversholt Rail policy of moving its maintenance methodology towards a "data-driven and real-time operation that will increase availability and reduce cost for our valued clients, like London Southeastern".
- **CRRC China Rail**
CR has expressed an interest in the Feonic technology for bearing monitoring since 2012. CRRC has existing sensors powered by batteries and wish to extend the life using energy harvesting. A specification has been received. Feonic is prompted regularly.
- **Bearing Manufacturers**
Bearing manufacturers have developed intelligent bearing monitoring for new train, and other, applications where power can be provided during the build. However, they recognise that the largest market opportunity is monitoring legacy trains for which their current solutions are battery powered.
- **SKF**
Feonic has engaged with Filippo Zingariello, Director Global Technology Service, SKF at their Technology Centre in Netherlands. SKF has investigated the option of using the Feonic technology and were keen to pursue the option. SKF shared vibration data. This relationship requires renewing as a solution from SKF has not been announced.
- **FAG Shaeffler**
Initial discussions have taken place concerning using the Feonic technology.
- **Forcing Function**
Earlier in 2019 Feonic were invited to partner a US data analysis company **Forcing Function** and have jointly secured a USA government grant of \$250,000 (phase 1) to develop a working solution that will monitor traction motors on US locomotives which frequently fail due to overheating, snow effects, or issues tied to traction control. The US government has been aware of this problem for almost as long as China Rail has known about the wheel bearing problem, however neither have created a suitable autonomous solution yet. If selected for phase 2 the grant could be worth \$1m.

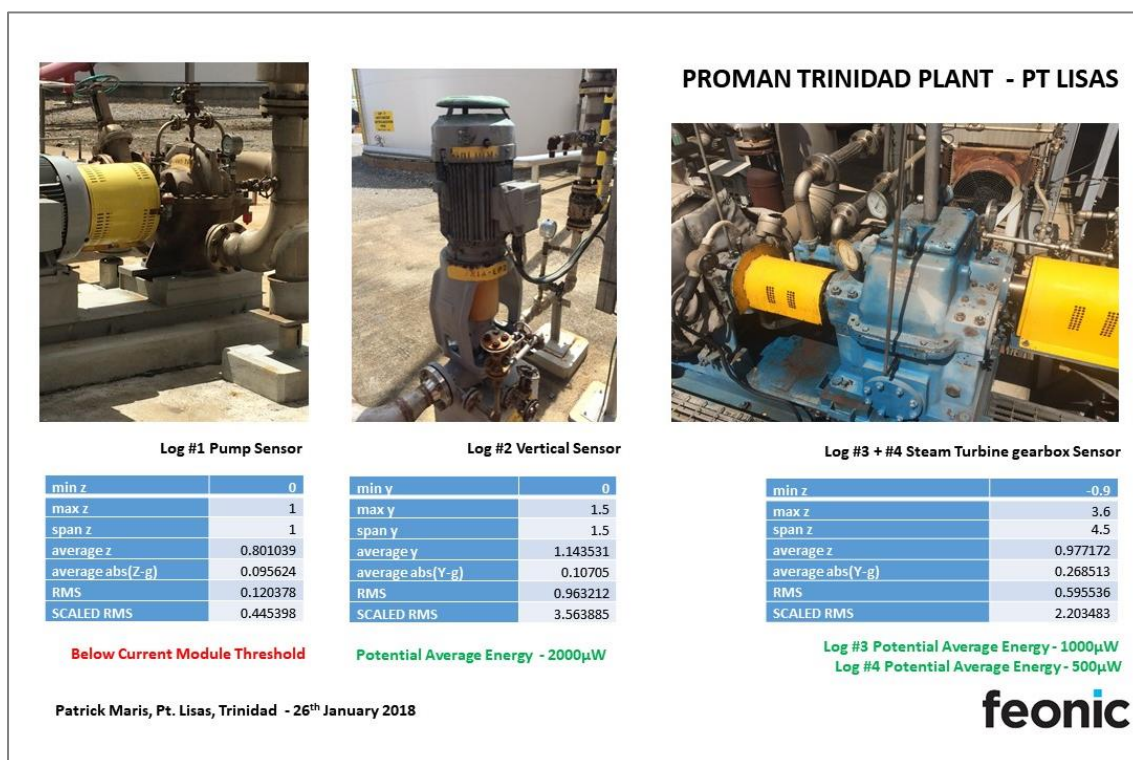
3 Petrochem & Pump Monitoring

3.1 Market Knowledge

The Proman Trinidad Methanol Plant was audited using Feonic sensors to establish the vibration level at a number of pump heads and transmission points. Of the four devices audited 3 provided adequate vibration energy to sense, process and send signal to a local receiver within the plant area.

We also met with the head of Innovation at Weir Group PLC in Glasgow and discussed the use of our technology for remote conditional monitoring their own equipment. Alan Buckley, Director Innovation for Weir Group stated quite clearly that whilst they had an abundance of vibration they had little in the way of conditional monitoring.

According to our research there are many applications where large pumps often very old are still in use in mission critical environments that could benefit for the technology that we are developing, the majority of which vibrate sufficiently to support our technology.



3.2 Trillium Flow Technologies, Formerly Weir Plow Control

Trillium Flow Technologies, formerly Weir Flow Control a subsidiary of Weir Group plc, is a global designer, manufacturer and aftermarket services provider of engineered valves and pumps used in energy and broader industrial applications. Its portfolio of 15 established brands serves customers in the power generation, oil and gas, water and wastewater, mining, and industrial sectors.

Trillium is working with Huddersfield University and has a high pressure sand slurry test centre installation as part of their KTP relationship with the University.

3.3 In Summary

The constraints we face in the freight industry are not dissimilar to the Petrochemical market where combustibility is a major concern and requires ATEX Zone 0 compliance and explosion proof build controls. The key challenge currently for the RCM market is that the cost of installing sensors that require cabling 'kills' the business case.

The ability to install wireless sensors quickly, using unskilled staff in this type of environment is a significant opportunity to cost effectively improve the reliability, and safety of lifts and escalators. Feonic is continuing to validate the market opportunity as a potential.

4 Additional Opportunities

4.1 Industrial Motors and Gearboxes

It is difficult to identify the global installed base of industrial motors and gearboxes. The market is estimated to be many 100's of millions.

The ability to install a sensor that is easy to install and will create a wireless mesh to provide monitoring data for predictive maintenance is an opportunity for Feonic.

However potential customer identification and market opportunity is to be completed.

- ABB
Currently provide either a mobile service or a costly fixed installation.



ABB MACH Sense-R

- Siemens
Provides remote monitoring of vibration and temperature using the installed MCM box.

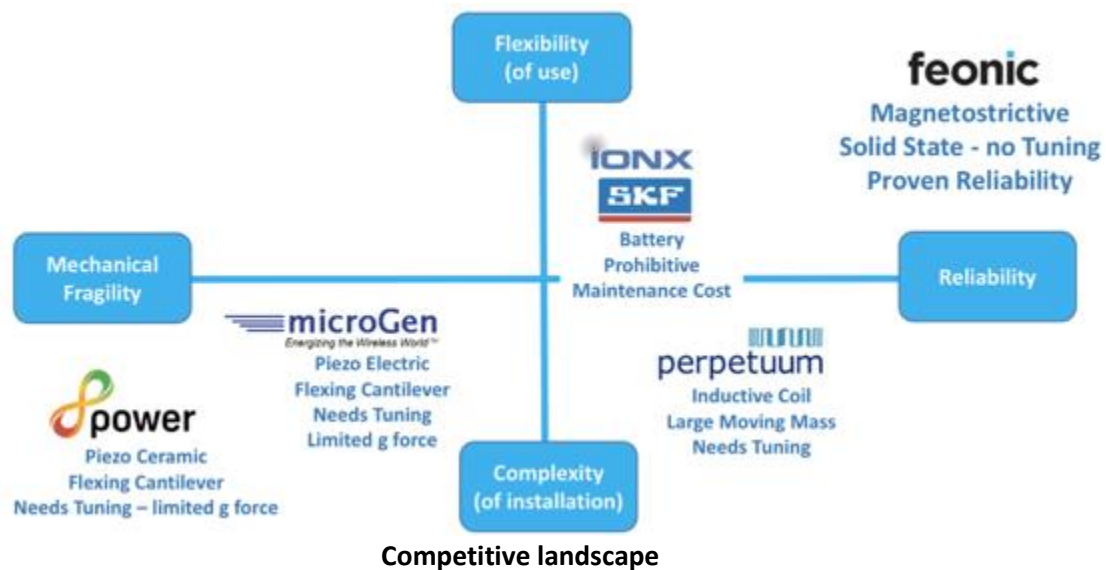


Siemens MCM Monitor

4.2 Cargo Tracking

- NFC Group <http://www.oriondatanetwork.com/cargo-trackers/>
The tracking of shipping containers is currently implemented using battery powered RF hotspot and satellite location devices. The batteries have a limited life. Meetings are being arranged to discuss energy harvesting supplementing

5 Competitive Landscape



The diagram illustrates that Feonic is higher up the axis of both reliability and flexibility than others in the autonomous wireless sensor market.

5.1 8 Power <https://www.8power.com/>

8 Power technology is based on piezo ceramic using a flexing cantilever focused on monitoring infrastructure and the IoT.

Their recent success is the monitoring of vibration on the Forth road bridge in Edinburgh.

A spin out of Cambridge University they raised £0.7m in 2016



Sensor installed on bridge

The advantages of their technology are that the unit can harvest power at low levels of vibration making the technology suitable for smart infrastructure.

However, the disadvantages of their technology are that the unit has to be tuned to a specific frequency and the material is fragile making it not suitable for rugged applications such as rail.

5.2 Microgen Systems Inc <https://www.microgensystems.com/>

microGen Systems, Inc., is the leading supplier of MEMS-based piezoelectric vibrational energy harvesting power generators and systems. We provide perpetual power solutions essential to the growth of the Internet of Things (IoT).



DC Power Cell is Available
\$75.00



The AC Power Generator is Available
\$55.00 each

Microgen supply cost effective AC and DC power cells however do not supply complete wireless sensors.

The strengths and weaknesses of the technology are similar to 8 Power.

5.3 IONX <https://www.amstedrail.com/products-services/ionx-asset-monitoring>

IONX is a JV with Amsted Rail, the global leader in freight car manufacturing, and Advance Rail, a sensor and monitoring specialist. The IONX product is sold via Amsted Rail.

IONX has a range of battery powered wireless sensors which are used to monitor a selection of parameters on freight cars and locos.

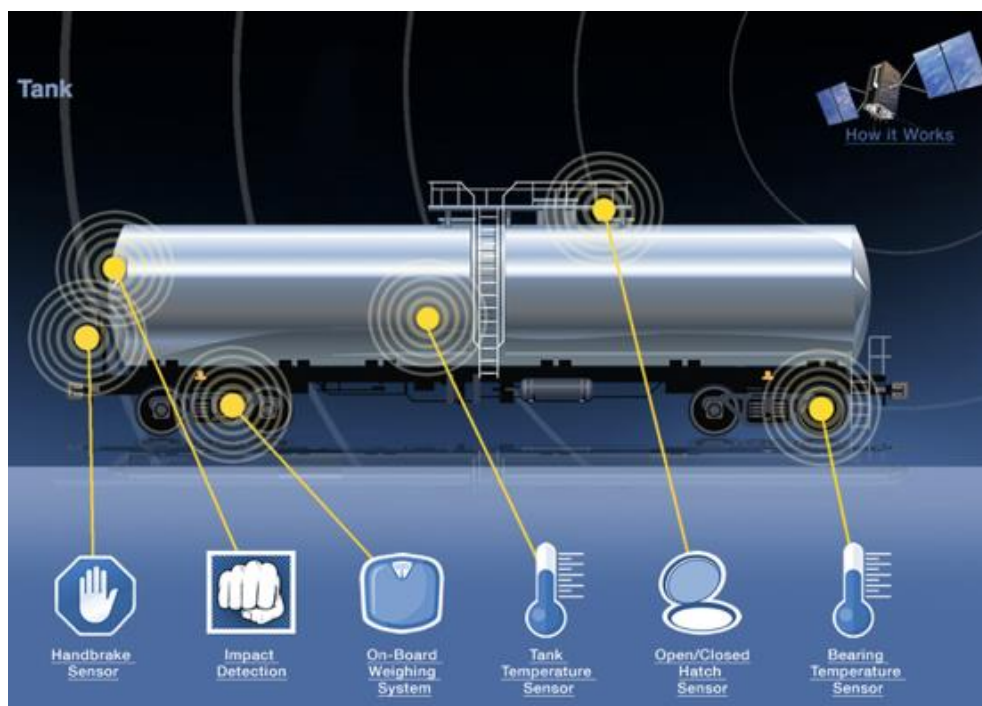
The messages are transmitted back to a data analysis and reporting centre via either cellular or satellite up to 4 messages per day on average.

They have a suite of web-based tracking and performance reporting tools.

Key points

- Battery life in the CMU central comms module is 5 years and 10 years in their remote sensors
- Have sold over 20,000 units

- Feonic has been talking with IONX for 12 months as they are very keen to use the Feonic technology in their sensors.



Monitoring Points

Model	Description	Sensing Capability	IS	Dimensions (mm)	Battery Life
 T4S	Asset Tracker	Location (GPS), impact, tilt, proximity, motion detection	Yes	270 x 76 x 41	4 Msg/Day, 5 yrs
 T4X	Asset Tracker - Extended Power	Location (GPS), impact, tilt, proximity, motion detection	Yes	236 x 185 x 41	16 Msg/Day, 5 yrs
 T5S	Asset Monitor	Location (GPS), impact, tilt, proximity, motion detection. 32 Node Wireless Sensor Mesh network	Yes	270 x 76 x 41	2 Msg/Day, 5yrs
 T5X	Asset Monitor - Extended Power	Location (GPS), Impact, tilt, proximity, motion detection. 32 Node Wireless Sensor Mesh network	Yes	236 x 185 x 41	8 Msg/Day, 5 yrs
 T6X	Asset/Train Monitor - Extended Power	Location (GPS), impact, tilt, proximity, motion detection. 32 Node Wireless Sensor Mesh network		236 x 185 x 41	4 Msg/Day, 5 yrs
 T7X	Asset Monitor with Local Reader-Extended Power	Location (GPS), impact, tilt, proximity, motion detection. 32 Node Wireless Sensor Mesh network	Yes	236 x 185 x 41	4 Msg/Day, 5 yrs
 321	Asset Monitor (Satellite)	Location (GPS), impact, 16 Node Wireless Sensor Mesh network	Yes	178 x 356 x 89	4 Msg/Day, 5 yrs
 351	Asset Monitor (Cell/Satellite)	Location (GPS), impact, 16 Node Wireless Sensor Mesh network		178 x 356 x 89	4 Msg/Day, 5 yrs

CMU- Central Comms Module and Sensor

	Model	Description	Sensing Capability	IS	Dimensions (mm)	Battery Life
	WSN - 101	Open/closed	Reed Switch; Internal Temperature	Yes	60 x 40 x 35	10 years
	WSN - 102	Bearing temperature monitoring	External Temperature; Internal Temperature; Reed Switch	Yes	60 x 40 x 35	10 years
	WSN - 113	Empty wagon	Reed Switch; Internal Temperature	Yes	60 x 40 x 35	10 years
	WSN - 114	Jacketed tank car temperature	External Temperature; Internal Temperature; Reed Switch	Yes	60 x 40 x 35	10 years
	WSN - 115	Strain - On-Board Weighing System	Strain Sensor; Internal Temperature	Yes	60 x 40 x 35	10 years
	WSN - 117	Thermowell tank temperature	External Temperature; Internal Temperature; Reed Switch	Yes	60 x 40 x 35	10 years
	WSN - 175	Relay controller	Relay - two lines rated to 125VAC, 220VDC at 2 amps		60 x 40 x 35	10 years
	WSN - 201	Handbrake linkage tension	Strain Sensor; Internal Temperature	Yes	230 x 100 x 50	10 years

Remote Sensors – communicate with CMU



Monitoring Reports

5.4 SKF

SKF are one of the leading global suppliers of bearings.

SKF have taken two approaches to monitoring their bearings.

- **New build**
SKF have intelligent bearings some with built in power generation from the rotation of the bearing. The bearings are usually cabled back to the train control system.



Shown, optional sensorised version for speed/temperature/vibration

SKF Sensorised Bearing

- **Legacy installations**
The legacy market is the largest potential market for remote monitoring representing over 80%. SKF have been developing a wireless bearing sensor unit suitable for the rail and wind turbine legacy installations where the cost of replacing existing bearings is too high.
The unit is designed to be bolted to the rail axle box and is currently powered by a battery.

The advantage of a battery powered unit is that it can be mounted in any orientation whereas all vibration powered units require to be mounted in a specific orientation to maximize the vibration forces.



SKF sensor installed on axle box

SKF Battery powered sensor

Battery powered CMWA 8800 SKF Wireless Machine Condition Sensor Costs - £200 - £399

Specification states that the entire assembly will need to be replaced when the batteries expire which will be dependent on the duty cycle, load characteristics and environmental conditions but somewhere between 2 and 3 years.

Total cost for 20 years usage excluding labour, installation time x minimum 6 visits to each location or expenses = £1,800 - £3,600 per unit **and will involve the disposal of millions of primary batteries into Landfill every year due to the need for replacement. The freight industry alone would consume 80,000,000 AA cells every 2 – 3 years.**



5.5 Perpetuum

Perpetuum are the market leader for autonomous monitoring of bearings and rail track using vibration. A spin out from Southampton University in 2004 they initially focused on monitoring industrial motors and partnered with Emerson and Honeywell.

Subsequently they have been successful installing their bearing monitoring sensors on over 9,000 train axle sets. The bearing monitors are also used to monitor track and wheel condition.

The installation comprises of a sensor mounted adjacent to the axle bearing which transmits the data wirelessly to a data concentrator using a 433Mhz low band width protocol. The data concentrator collects the data from multiple sensors, conducts analytics, and transmits the data from the train using cellular via the cloud to a central monitoring and reporting centre. The reporting centre consolidates the data and provides a web based front end that outputs a Bearing Health indicator, and a Track Condition indicator if that function is enabled.

Perpetuum business model is the sale of the sensor for an estimated cost of £300 per unit and an ongoing managed service for the provision of the information and the data charges. We are not aware of the managed service cost.



Our award-winning, quick-to-install and maintenance-free technology provides valuable real-time information to save costs, and increase safety and efficiency.

Perpetuum advantages:

- Market traction
- Proven data analytics
- Funding

Disadvantages:

- Due to the size of the unit it cannot be installed on the outer face of the train thus requiring fitter access under the train the depot.
- Customers perceive the cost as high
- The technology is based on a moving mass so moving parts
- The technology has a narrow band of frequency from which power can be harvested
- Will not share raw data

5.6 Feonic Technology and the Powercell Sensor

Feonic specialises in the development & miniaturisation of smart-material products and has been manufacturing and selling a range of maintenance free, solid-state wide bandwidth audio devices under the protection of multiple world-wide patents, for over ten years.

When the smart-material in a Feonic audio product is subjected to mechanical vibrations, electrical energy is generated. This power can be harvested and stored in ultra or super-capacitors very efficiently. Unlike most mechanical vibration harvesting devices Feonic technology does not need to be tuned to specific resonant frequencies, but harvests power over a wide frequency range.

Following a number of documented rail accidents caused by failing train wheel bearings, there is a recognised need to monitor the bearing temperature in order to recognize (and therefore predict) change in order to avoid potential failure. The use of antiquated battery technology - with the need for replacement every few years, is hampering the widespread deployment of wireless connected sensors in many markets.

Feonic's small, lightweight Power Module can harvest and store sufficient energy from the train's mechanical vibrations to power an autonomous Feonic Powercell Sensor, sensing change in the host machines condition (vibration, heat etc.) and wirelessly communicating via remote monitoring using any proprietary wireless system.



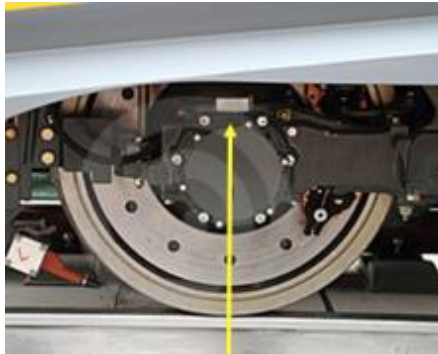
The application is not limited to freight trains, there are millions of legacy machines, many over 30 years old that suffer wear problems that would benefit from autonomous Remote Conditional Monitoring (RCM).

Our concept is to harvest sufficient power to monitor and report any number of functions, for any number of possibilities in the emerging Internet of Things without the need for maintenance support or battery replacement, anywhere in the world, potentially to any smart device for 40 years or more, without requiring resonant frequency tuning on many different types of machines in all environmental condition.



Power Module, Sense & Send
Feonic Powercell Sensor
118mm x 36mm x 33mm

The Feonic Powercell Sensor can be installed within minutes by unskilled staff. The small size of the sensor enables the unit to be installed easily in discreet locations reducing the need for specific approvals.



Feonic sensor mounted on outside of train axle box



Market leader requiring access under train – i.e. in a yard - out of service

5.7 Huddersfield University & the Institute of Railway Research

The Institute of Railway Research team at Huddersfield University have worked on a 12 month study for the Rail Safety & Standards Board collecting and analysing over 10,000 miles of axle box acceleration data.

It is proposed that this knowledge and acquired data will be applied in optimising the mechanical design of the Feonic device to maximise energy recovery across both passenger and freight vehicle axle box installations. Feonic and Huddersfield University intend to apply for an Innovate or similar grant to assist in this project.

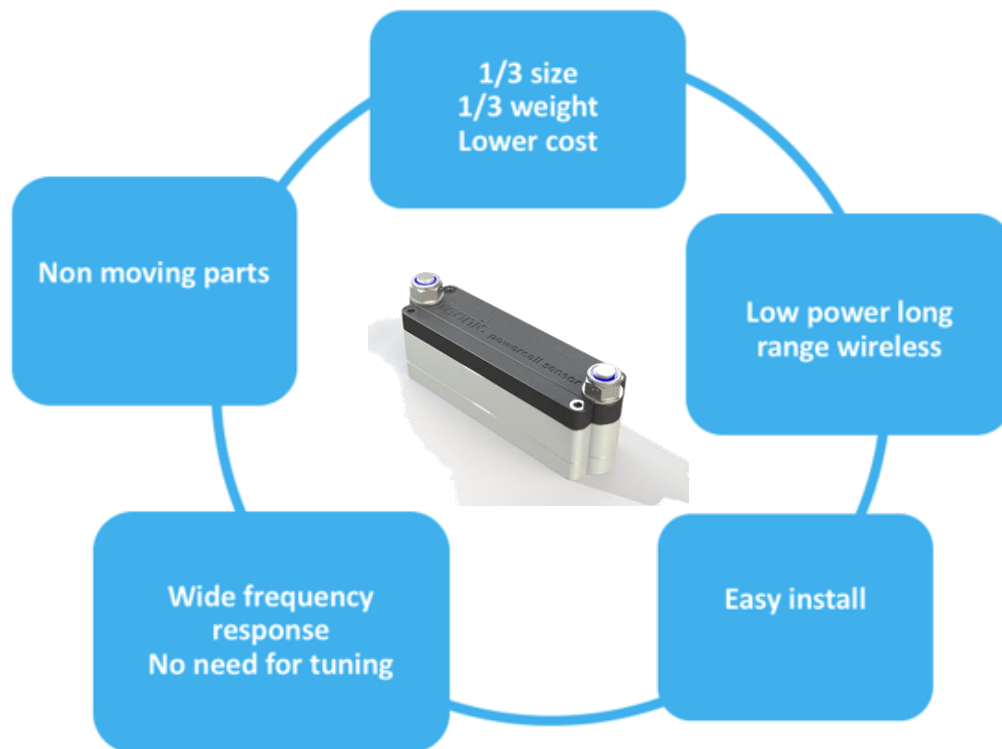
Paul Allen, Professor of Railway Engineering & Technology, Assistant Director Institute of Railway Research University of Huddersfield commented that **“applying this knowledge to the Feonic Powercell Sensor will provide a unique solution using cutting edge autonomous technology which will be offered initially to the freight rail Industry”**.

Feonic presented a working paper on the use of smart material to create small efficient autonomous sensors to the delegates of the 32nd International Congress and Exhibition on Conditional Monitoring and Diagnostic Engineering Management conference **COMADEM** at the Institute of Railway Research in Huddersfield in September.

The presentation was well received and received excellent feedback from the delegates.

A number of discussions and opportunities have arisen from this event.

Trillium Flow Technologies (as summarised in 3.2 above) are also working with Huddersfield University as part of a KTP with Dharminder Singh (KTP engineer) under the guidance of Prof. Rakesh Mishra looking at wear characteristics of sand/water slurry being pumped under high pressure testing a new pump and valve system. It is proposed to evaluate the vibration levels and qualify the opportunity of predictive monitoring from harvested energy emitted from the the University test centre.



Feonic USP's

6 The Company Set Up

6.1 Opportunity

- A new company, Feonic Vibration Technology Ltd, will be established to exploit the opportunity of using energy harvesting for remote monitoring of assets.
- Founding shareholders will include the three existing Feonic Ltd Directors, Feonic Shareholder group (one-person representative) and the new investor.
- Feonic Vibration Technology Ltd will utilize the technology, expertise and patents established by Feonic Ltd.
- Feonic Vibration Technology Ltd is seeking To raise £200,000 (With a minimum fundraise of £165,000) from known investors using convertible loan notes (into Newco) in order to qualify and quantify commercial viability from the following planned trials:
 - UK Network rail: Derby-Crewe-Euston Derby (Passenger) > October
 - UK Direct Rail Services: Motherwell - Carlisle (Freight) > November
 - China Rail Guangzhou Group: Guangzhou – Changsha (Freight) > October
 - USA Montgomery Maryland: Traction motor (Loco) > Oct-March **Funded**
 - USA West Chester, Pennsylvania: Freight > Dec-Jan
- Thereafter the company is looking to raise an initial working capital of £2.4m by the issue of ordinary shares in the New company.
- Additionally the Company is seeking to secure grant or loan funding possibly from Innovate UK on another provider of £1.2m.

6.2 Use of Funds

- Embed Artificial Intelligence for machine learning sensor processing
- Establish ATEX Zone 0 compliance & approved manufacturing partner.
- Employ Business development leader and establish technical Sales team
- Establish production of the Smart-Material in the UK – in conjunction with Less Common Metals Ltd, Liverpool
- Enter second market vertical in industrial pump and valve monitoring
- Patent license – a global, perpetual and irrevocable license to use the technology for energy harvesting for a one-off payment of £250k to Feonic Ltd be paid on completion of the equity fundraising with a 2% royalty payment from all company sales from August of year 3 to the end of the fifth years trading.

6.3 The CAP table (Pre - Company Incorporation)

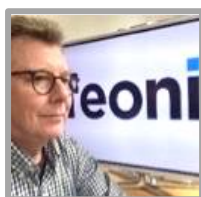
	Founder		Post Investment	
	Shares	%	Shares	%
Feonic Ltd - Founder	140	20.0%	140	14.00%
Brian Smith - Founder	280	40.0%	280	28.00%
Brenda Hopkins- Founder	140	20.0%	140	14.00%
Graham Beswich-Founder	140	20.0%	140	14.00%
Unallocated/New investors			300	30.00%
Total shares in issue	700	100.00%	1000	100.00%

6.4 The Feonic Team



Robert Brown, Chairman

Robert is a successful business leader with significant experience in technology and business development. Instrumental in growing companies in the automotive, telecoms, defense and rail industries. Operated internationally developing sales, establishing operating divisions and delivering projects in Europe, Scandinavia, Middle East, USA and Canada. Robert will be assisting with global business development.



Brian Smith, CTO & interim CEO

Brian is a leader in identifying market requirements for magnetostrictive technology and leads the design, development and manufacturing activities. Brian has extensive experience of product design, patents and product manufacturing in China. Brian is also an expert on the sourcing of Terfenol D, the core component.



Dr Kamlesh Prajapati, Feonic Resources

Kamlesh is a leading expert in Magnetostrictive devices having gained his expertise from the founder academics at the University of Hull and has over 20 years' experience working with smart materials for commercial applications.

6.5 UK production of Smart-Material



The key component that enables Feonic Technology to harvest power is a smart material called Terfenol-D (TD), a synthetic crystal made from Iron, Dysprosium and Terbium. The world's largest producer of TD is based in Iowa in the US and has been supplied with a very high purity alloy of these three materials for more than 30 by Less Common Metals Ltd (LCM) a UK company based in Liverpool. LCM is a world leader in the manufacture and supply of complex alloy systems and metals and are specialists in those based on rare earth elements. LCM has its own on-site analytical facility for the qualification of materials and holds both ISO9001 and ISO14001 certifications and has sufficient capacity, resource and skill set to bring the manufacturing of the TD to the UK which would provide us with a local reliable and robust core material source without reliance on a third-party country.

Feonic and LCM have been in discussions for two years and a draft agreement is in place with a US technology agent who helped set up the US operation, to replicate the smart material manufacturing technology in the UK once we have established sufficient demand.

The budget provides support for three phases of work:

Phase 1: Equipment specification (crystal growing machine, Takatori multi wire saw, measuring kit & vendor selection.

Phase2: Procurement cycle and beginning equipment installation

Phase 3: Equipment commissioning, process setup, testing, tech transfer

7 Financial Assumptions and Forecasts

7.1 Market Size & Penetration

Feonic has identified four key rail application that will be targeted:

1. Traction motor bearings (EMU Electric trains, DMU Diesel Trains & locos) - GE recondition approximately 250 traction motors per week at a cost of \$10,000 each
2. Axle bearings
3. Turbocharger bearings (DMU and locos)
4. Freight car wheel bearings (18.8m)

A Feonic sensor used for wheel and axle bearing monitoring Feonic could also monitor both track and wheel condition.

The RCM Market leader, SKF (Sweden) sells a battery powered RCM device that requires two AA batteries which need replacing every 2-3 years.

The global train market of 36.9m axle bearing points equates to just under 80 million (2 x AA batteries per unit) implying that every 2 or 3 years 80 million toxic primary batteries will be sent to landfill to further pollute the planet^[1].

Globally there are around 40 million key monitoring locations on the worlds rail fleets.

Based on existing technology solutions this represents an £8 billion pound opportunity.

Conservatively we expect to achieve sales of over £20m by year 5 from the initial target market (Rail) representing significant year 5 revenue.

The market is further split by varying customer requirements – opportunities exist to supply power modules only (for energy harvesting) to replace or supplement primary batteries, or to provide charge for on board super capacitors (hybrid Powercell) are very significant.

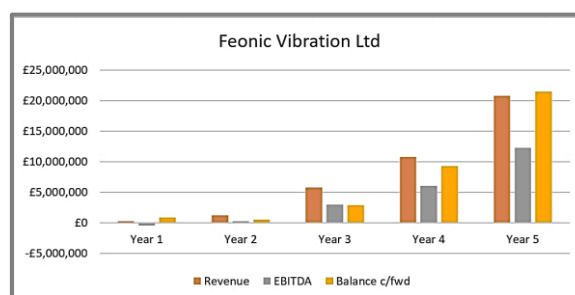
We have also identified a significant demand for a managed service for smaller user groups where site operators require a cloud based solution that could be set up to report on conditional changes via local wireless via a smart phone or alternate cloud device paying a small monthly charge per device used.

Given a successful collaboration and progression to an early-stage customer project, this technology has the potential to build expertise within to enable other RCM opportunities to help predict failure before it occurs.

7.2 Financial Forecasts

Discussions have been started with a number of companies, including oil and gas, mining & mineral recovery, pumping and water treatment.

By year 5 we also intend to commence sales into our second market vertical – most likely in industrial pump and valve monitoring^[2] for oil & gas^[3], mining and minerals and Petro-chem processing.



FEONIC VIBRATION TECHNOLOGY LTD 5 YEAR SUMMARY					
	Year 1	Year 2	Year 3	Year 4	Year 5
Revenue	£260,000	£1,225,000	£5,750,000	£10,750,000	£20,833,333
Cost of Gross Sales	-£76,489	-£393,917	-£1,704,127	-£3,174,404	-£6,185,929
Gross Profit	£183,511	£831,083	£4,045,873	£7,575,596	£14,647,404
Gross Margin	70.58%	67.84%	70.36%	70.47%	70.31%
Overheads	£653,075	£634,432	£1,122,538	£1,674,909	£2,693,858
IP License fees	£250,000	£0	£68,493	£214,359	£388,806
Investment	£2,400,000	£0	0	0	0
Grant income	£0	£0	£0	£0	£0
Lowest Cash	£811,881	£304,192	£482,651	£3,211,272	£8,998,974
EBITDA	-£469,564	£196,651	£2,923,335	£5,900,687	£11,953,546
Net Assets	£1,792,785	£1,726,739	£4,406,806	£10,117,727	£21,921,449
Management	3	3	4	4	4
Staff	2	4	8	11	12

7.3 Intellectual Property

Feonic has already registered and established multiple family patents: The core "invention" patent, the "improvement" patent and the "energy harvesting application" patent granted in the UK, EU, USA, Japan and China. Further Patent applications focusing specifically around the mechanism of maximising the harvested energy and the efficient conversion of this energy to useful power will provide new distinct IP, underpinned by the existing granted patents.

Current Granted patents include: UK & EU: EP2253029, EP2235761, EP1576851, EP1773097
CHINA: ZL2003 8 0106783.1, ZL 2008 8 0110450.9, ZL2008 8 0110449.6, **JAPAN:** JP4102904, JP5791011, **USA** US7620193, US8416972, US8471432

7.4 References

[1] The **Feonic Powercell Sensor** has been awarded the 168th **Efficient Solution** label by the Solar Impulse Foundation who seek 1000 solutions that combine protection of the environment and financial viability to show that these solutions are not expensive fixes to problems, but rather opportunities for clean profitable economic growth. <https://solarimpulse.com/efficient-solutions/feonic-powercell-sensor>

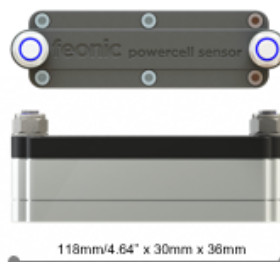
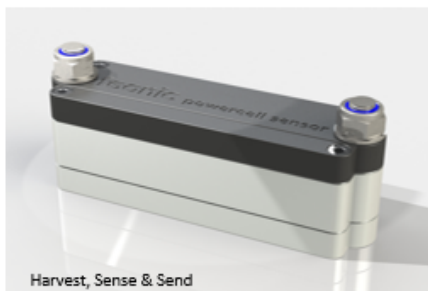


- [2] ***"Most oil & gas rigs built in the last 15 years have on-board RCM, older rigs don't".***
 (Managing Director, Nexen CNOOC Aberdeen)
- [3] ***"We have an abundance of vibration but little in the way of conditional monitoring"***
 (Innovation Director, Weir Group, Glasgow)

7.5 Technical Specification



Feonic Powercell Sensor
October 2019



The Feonic™ Powercell Sensor

generates electrical power from the natural vibration of machinery and equipment.

Patented worldwide, Feonic smart-material generators are used to power sensors and wirelessly deliver real-time conditional data to the Cloud without batteries, wiring or any additional support infrastructure, even in the most hostile environments for any manner of Industries.

The use of antiquated battery technology with the need for replacement every few years, is hampering the widespread deployment of wireless connected sensors in many markets.

Feonic's small, solid-state harvester collects and stores sufficient energy from the train's vibrations to power an autonomous Feonic Powercell Sensor, sensing change in the host machines condition (vibration, heat etc) and wirelessly communicating via remote monitoring using any proprietary wireless system.

Tested to vibrations of over 130g the rugged Powercell Sensor is suitable for monitoring a wide range of industrial machines and systems in extreme environments. Immune to heat, moisture and pressure, applications include bearings on trains and wagons, turbines and engines, gearboxes, pumps, and traction motors all could benefit from autonomous Remote Conditional Monitoring.

Technical Specification

Target harvesting threshold:	0.4g RMS
Vibration operating range:	0.4g - 200g
Harvesting range:	75Hz - 350Hz
Optimum conditions @ 3g:	2.5mW
Peak raw power @70g:	180mW
Target output power:	3 - 4mW
Environmental (standard):	IP67
Environmental (enhanced):	ATEX ZONE 0
Dimensions:	118 (L) x 30 (W) x 36 (H)
Weight:	550gms
Mounting arrangement:	2 x M8 @ 101mm centres
Standard operational temp:	-40°C to +125°C
Storage temperature range:	-40°C to +125°C
Highoperating temp option:	-40°C to +150°C
Communications (node):	LoRa, NBiot, WiFi, Ble etc
Communications (hub):	GSM 4G options
Cyber security:	End to End encryption
Sensors:	Temp, Vibration (optional)
EMC Compliance:	EN 50121-3-2:2008
Rolling stock gen standard:	EN50155
Vibration/shock compliance:	EN61373 Cat 3 Axle mount
Warranty terms:	10 years

The Powercell Sensor has been awarded the 168th Efficient Solution label by the Solar Impulse Foundation who seek 1000 solutions that combine protection of the environment and financial viability to show that these solutions are not expensive fixes to problems, but rather opportunities for clean profitable economic growth.



<https://solarimpulse.com/efficient-solutions/feonic-powercell-sensor>



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