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Sustainable Bioenergy
Solutions for Tomorrow

Metsäteho

MEASUREPOLIS
Measurepolis Development Oy

Wireless sensors for moisture and temperature estimation of storages and chip piles

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The Sustainable Bioenergy Solutions for Tomorrow (BEST)

State-of-the-Art study

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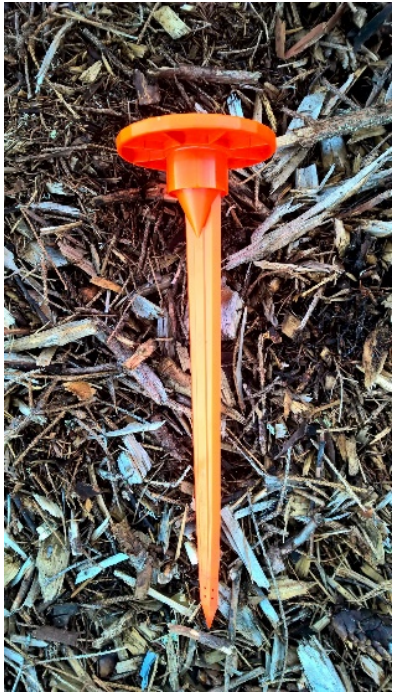
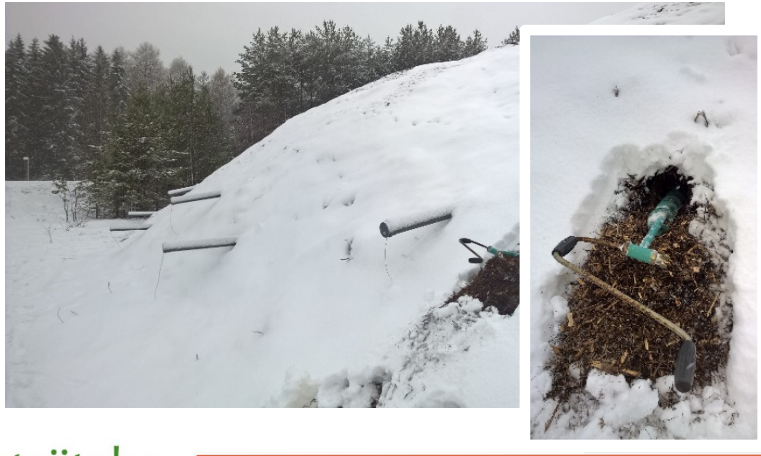
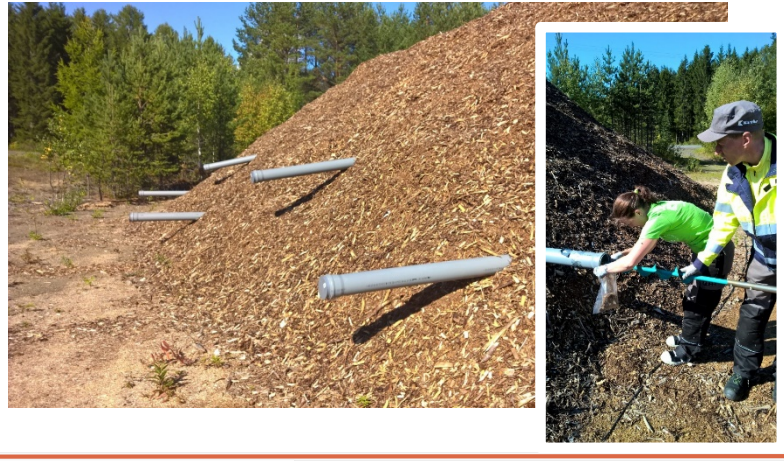


Introduction – State-of-the-Art study

- The aim of the study was to determine the utilization possibilities and functionality of humidity and temperature sensors in the monitoring of the quality of energy wood materials.
- The study was carried out as a State-of-the-Art study by interviewing experts and sensor manufacturers and developers. Sensors with the biggest potential were selected for testing in field conditions. Field tests were carried out in co-operation between Karelia University of Applied Sciences, the University of Eastern Finland and VTT. The results of field tests will be reported later in the autumn.





Humidity and temperature sensors

- Humidity sensors
  - Resistive or capacitive method used as the measuring principle. Moisture adsorption in these materials is generally the result of a porous ceramic material, which is produced and processed utilizing thin or thick film technology on a single chip, of the size of approximately one millimeter.
- Temperature sensors
  - Single-chip sensors with a silicon diode (temperature-dependent forward voltage, Band Cap Sensor).
  - Platinum-resistive sensors PT100 and PT1000 are also used as temperature sensors.
- Silicon-based chip sensors consist of the sensors, a preamplifier, an A / D converter, a buffer memory and the necessary electronics. The calibrated humidity and temperature data can be sent directly from the chip as a digital message to the integrated measurement system.
- A typical sensor chip of this type is Sensirion SHT25 Sensor. Sensirion humidity sensor is based on the measurement of relative humidity utilizing capacitive sensor technology. The temperature is measured with a "Band cap" semiconductor sensor.
- RFID sensors (includes data transfer technology).

Sensirion SHT25 (http://www.sensirion.com)

SENSIRION
THE SENSOR COMPANY

Datasheet SHT25

Humidity and Temperature Sensor IC

- Fully calibrated with 1.8%RH accuracy
- Digital output, I²C interface
- Low power consumption
- Excellent long term stability
- DFN type package – reflow solderable

Product Summary

The SHT25 high accuracy humidity and temperature sensor of Sensirion has become an industry standard in terms of form factor and intelligence: Embedded in a reflow solderable Dual Flat No leads (DFN) package of 3 x 3mm foot print and 1.1mm height it provides calibrated, linearized sensor signals in digital, I²C format.

The SHT2x sensors contain a capacitive type humidity sensor, a band gap temperature sensor and specialized analog and digital integrated circuit – all on a single CMOSens® chip. This yields in an unmatched sensor performance in terms of accuracy and stability as well as minimal power consumption.

Every sensor is individually calibrated and tested. Lot identification is printed on the sensor and an electronic identification code is stored on the chip – which can be read out by command. Furthermore, the resolution of SHT2x can be changed by command (8/12bit up to 12/14bit for RH/T) and a checksum helps to improve communication reliability.

With this set of features and the proven reliability and long-term stability, the SHT2x sensors offer an outstanding performance-to-price ratio. For testing SHT2x two evaluation kits EK-H4 and EK-H5 are available.

Radio Frequency Identification (RFID) sensors (Smartrac)

Measured characteristics

- Temperature, humidity application under development

Description of measurement technology

- Passive RFID -technology, the operating frequency of 840 MHz, a sensor antenna that senses the state of the environment. Humidity and electrical properties of the material most significant factors in the functioning of the sensor. Having a functioning energy by means of a reader antenna transmitter.

Benefits and constraints / disadvantages

+ Passive sensors, do not need extra power supply, sensor operating time as unlimited

+ Lightweight, recyclable, can even stay in the process within limits (a very thin aluminum antenna, a silicon-based microchip)

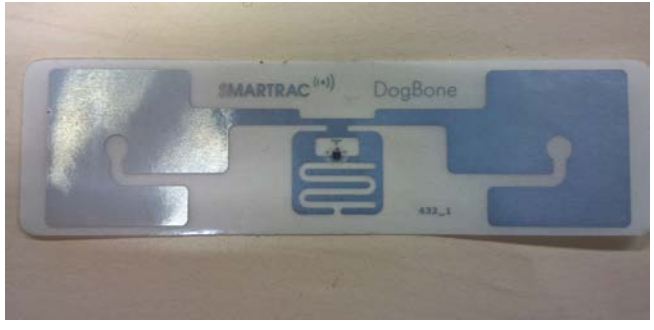
+ Low cost sensor, the reading device can sense a large number (tens - hundreds) of sensors

+ Sensor location data can be determined in some extent

– Reading distance from inside the chip pile (not tested)

– Permanency?

Passive/Active	Passive
Existing applications	Buildings
	Car applications



Data transfer technologies

Wireless communication technologies from the sensor to the base station or reader

- IR technology
  - requires uninterrupted signal path
  - in use eg. remote controllers
  - is not suitable for transferring data from the inside of a chip pile
- Radio wave technology
  - widely used (ISM frequencies)
    - 2.45 GHz, 868 MHz, 433 MHz
  - signal transmittance tens of centimeters – meters
- Electromagnetic induction
  - signal transmittance several meters

The data transfer from measuring system to cloud services

- Wireless GSM data transfer / communication

Data transfer technologies based on radio wave technology

- ISM band frequencies (Industrial, Scientific and Medical) are used in data transmission. The use of these worldwide radio frequency bands doesn't require any authorization or license and these frequencies were originally intended for industrial, scientific and medical use. The most commonly used frequency ranges, UHF ranges are the 2.45 GHz band, 868 MHz band (Europe) and 434 MHz band.
- **2.45 GHz** (frequency band)
  - used in portable devices with Bluetooth and WLAN applications (eg. mobile phones audio and data transfer applications).
  - the range is typically within a few meters –tens of meters in an open environment. Typically take place for data transfer in the same room.
  - The technique is inexpensive, there are many suppliers, but the frequency band is ill-suited in absorbing environment and is practically unsuitable for the chip piles (data transmission inside the pile). Wet (approx. 50%) materials the range is typically only tens of centimeters.
- **868 MHz** (frequency band)
  - Is significantly better than the 2.45 GHz frequency band also when transferring data through materials. Several applications that utilise this frequency band are available on the market.
  - The most successfull wireless temperature and humidity measurement solutions and sensor networks utilise the 868 MHz frequency band.
  - The range (kantama) can be several meters in humid and absorbing materials and it (range) is possible to improve and adjust the range by increasing the transmit power of the sensor module. This makes it possible also to take into account the attenuation caused by the material , and to adjust the power of the transmitter so that the intensity of the signal outside the e.g. chip pile remains under the limits, which are defined by the standard.
- **434 MHz** (the frequency band)
  - The best frequency band. The signal will pass through also in the case of humid biomaterials. However, the difference is not significant compared to the technology of 860MHz . The frequency band is about half of the 860 MHz's frequency, while the 2.45 GHz is approximately three times the 860 MHz frequency band and six times compared to the 434 MHz band.
  - 434 MHz technology is commonly used for instance in remote control systems used in vechicles, thus ,there are several component suppliers available and the technology is affordable.
- 868 MHz and 434 MHz technologies are better also in the sence that these frequency bands aren't used in other applications, for instance microwave ovens etc. Bluetooth and WLAN applications utilise the 2.4 GHz frequency band and could interrupt data transfer.
- All of these UHF radio wave sensor technology solutions have good component support due to the abundance of their applications.

Potential sensor systems

1) Seemoto – MeshWorks Wireless Oy (http://www.seemoto.com/fi)
2) Trelab Oy (http://www.trelab.fi/)
3) Sensire Oy (http://sensire.fi/)
4) Haytech Oy (http://www.haytech.farm/)
5) SMARTrac Technology Finland Oy (https://www.smartrac-group.com/)
6) Inductive data transfer (Electromagnetic induction) - VTT

Seemoto

Measured characteristic

- Temperature and humidity (TS and THS sensors)

Description of measurement technology

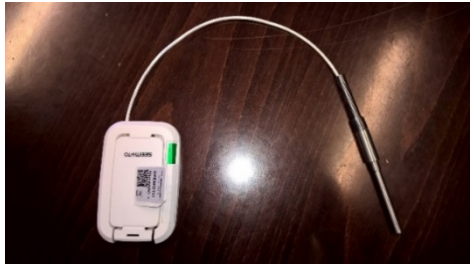
- Humidity and temperature sensors: Sensirion (silicon sensor)
- Does not require any charging, works with a disposable lithium battery. The battery operating time of 10 years. Also possible to use the so-called. data logger – record observations e.g. 5 min intervals (8,000 obs. / 1 month)

The data transfer technology

- Cable / bluetooth
- 2,45 GHz frequency band (Bluetooth, WLAN)
- Reading distance in open space 500 m (700-800 m), inside the chip pile 20 cm

Benefits and constraints / disadvantages

+ Real-time monitoring of temperature and humidity
– Measures air humidity, not material moisture
– Reading distance from inside the chip pile



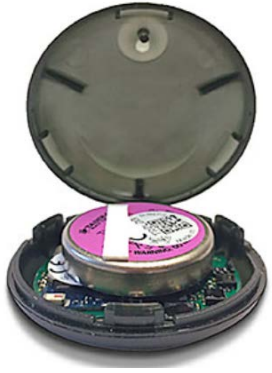
Passive/Active	Active
Existing applications	Applications in the pharmaceutical and food industry.

Trelab (Smart Tag)

Measured characteristic

- Linear acceleration, rotational acceleration, eCompass, Temperature, Humidity, Air pressure, Illuminance (ambient light), Presence (with gateway)

Measurement technology (sensors) not surveyed here



The data transfer technology

- Measurement data to the base station with Bluetooth Smart technology
- The base station transmits data between the smart tags and cloud service (Cloud Service + external API)

Benefits and constraints / disadvantages

+ Real-time monitoring of temperature and humidity
– Measures air humidity, not material moisture
– Reading distance from inside the chip pile

Passive/Active Active

Existing applications On the monitoring of the use conditions and equipment base
- Industrial Internet & Real Estate

Sensire Oy

Measured characteristic

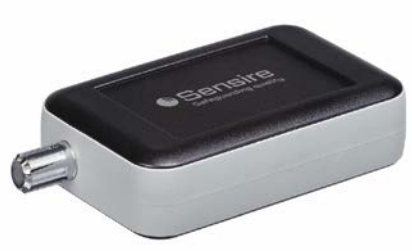
- Temperature and humidity

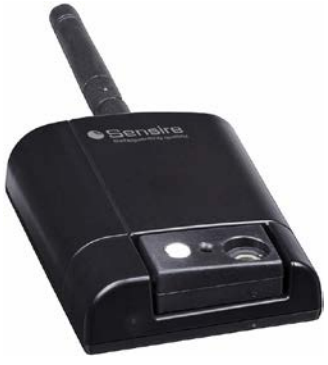
Description of measurement technology

- Humidity and temperature sensors: Sensirion (silicon sensor), Analog Devices ja Vaisala sensors.
- Does not require any charging, works with a disposable lithium battery. The battery operating time of 2-3 years.
- Also possible to use the so-called. data logger – record observations eg. 5 min intervals (8,000 obs. / 1 month)

The data transfer technology

- 868 MHz frequency band (ISM band)
- reading distance in open space hudreds of meters
- reading distance inside the chip pile some meters





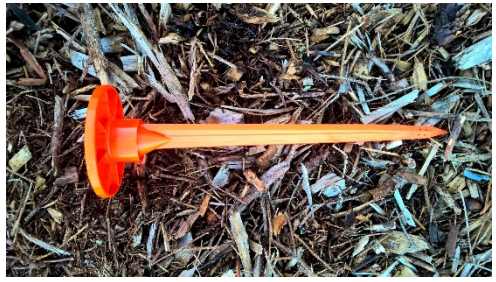
Benefits and constraints / disadvantages

+ Real-time monitoring of temperature and humidity
- Measures air humidity, not material moisture
- Reading distance from inside the chip pile?

Passive/Active Active

Existing applications Sensor applications in the pharmaceutical and food industry.

Haytech Oy (VTT spin-off)

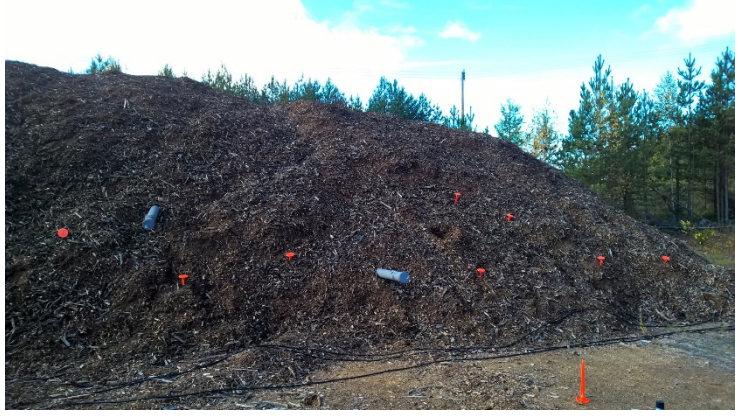


Measured characteristic

- Temperature and humidity

Description of measurement technology

- Humidity and temperature sensors: Sensirion (silicon -sensor) – sensors.
- Does not require any charging, works with a disposable lithium battery.
- Also possible to use the so-called. data logger - record observations to the base station and send them every hour to the cloud.



The data transfer technology

- 433 MHz frequency band (ISM – band)
- reading distance in open space hundreds of meters
- reading distance inside the chip pile 2-4 meters

Benefits and constraints / disadvantages

+ Real-time monitoring of temperature and humidity
- Measures air humidity, not material moisture

Passive/Active Active

Existing applications Sensor applications in the agriculture.

The data transfer technologies based on electromagnetic induction

Wireless communication technologies from the sensor to the outside of the pile (to the base station or reader)

- **Measuring distance**
  - Several meters of wood chip pile application
- **Data transfer technology**
  - The inductive (magnetic field) method, the information can be transferred also through very wet materials, even in the water
- **Reading distance in the air**
  - Depends on the size of the antenna, several meters
- **Reading distance in the material**
  - Depending on the size of the antenna. For example if the antenna size is 5 meters, the reading distance is approx. 5 m.
- **Passive / Active**
  - Active, the sensor unit requires a battery (Lithium)
- **Existing applications**
  - Sea water
  - Constructions (concrete)
  - Stone materials (ore piles)
  - Soil

The data transfer from measuring system to cloud services

- Wireless GSM data transfer / communication

Summary - The humidity and temperature sensors

Temperature and humidity sensors	Measured characteristic	Measurement technology	Active / Passive	Data logger properties	Recording capacity	Advantages	Constraints / disadvantages	Existing applications	Price
Seemoto - TS temperature sensor	Temperature	Sensirion (silicon -sensor)	Active (lithium battery)	Yes	Record observations 5 min intervals (8,000 obs. / 1 month)	Real-time monitoring	Measures air humidity, not material moisture. Reading distance from inside the chip pile	Sensor applications in the pharmaceutical and food industry.	Sensor app. 150 -200 € /pc. Measuring service 10 €/pc/month
Seemoto - THS temperature and humidity sensor	Temperature and humidity	Sensirion (silicon -sensor)	Active (lithium battery)	Yes	Record observations 5 min intervals (8,000 obs. / 1 month)	Real-time monitoring	Measures air humidity, not material moisture. Reading distance from inside the chip pile	Sensor applications in the pharmaceutical and food industry.	Sensor app. 150 -200 € /pc. Measuring service 10 €/pc/month
Smart Tag (TreLab)	Temperature and humidity	-	Active (lithium battery) 550 mAh, operating time 1 year	Yes	-	Real-time monitoring	Measures air humidity, not material moisture. Reading distance from inside the chip pile,	On the monitoring of the use conditions and equipment base - Industrial Internet & Real Estate	-
Smartrac (RFID)	Temperature (humidity application under development)	RFID (UHF) -sensor (DogBone), silicon-based chip	Passive, Having a functioning energy by means of a reader antenna transmitter.	No - needs a reader, which sends the data futher	Can sense a large number (tens - hundreds) of sensors	Light, recyclable , inexpensive, does not require a extra power source	Reading distance from inside the chip pile. Positioning of sensors. Permanency?	Different applications for the construction and automotive industries as well as the care sector	Cost-effective
Haytech (Sensirion SKT25)	Temperature and humidity	Senzorion SKT25 (piisensori) - näytteeseen työnnettävä anturi, jonka kärjessä itse anturi - asennussyvyys n. 50 cm	Active	Yes	The data is stored to the base station in 1 hour intervals.	Real-time monitoring. Good availability of the sensors.	Measures air humidity, not material moisture.	Moisture measurement´s of bio-energy material	Cost-effective Sensor cost about one euro.
Sensire (HTS70-20)	Temperature, Humidity, säteilyannos, energiankulutus	Humidity sensor Vaisala HUMICAP 180R Teperature sensor Pt1000 RTD	Active (lithium battery)	Yes	Measuring interval adjustable (1-60 min), recording capasity 32 000 observations	Real-time monitoring	Measures air humidity, not material moisture. Reading distance from inside the chip pile	Sensor applications in the pharmaceutical and food industry.	-
Sensirion (SHT25)	Temperature and humidity	Sensirion (silicon -sensor)	Active	Yes	-	Good availability of sensors	Measures air humidity, not material moisture.	Sensor applications in the pharmaceutical and food industry.	Cost-effective Sensor cost about one euro.

Summary - Data transfer technologies

Data transfer technologies	Wireless communication technologies from the sensor to the base station or reader	The frequency	Reading distance in open space	Reading distance inside the chip pile	The data transfer from measuring system to cloud services
Seemoto	The measurement data from the sensor is transmitted to the base station wirelessly (Bluetooth)	2,4 GHz	Reading distance in open spacea 500 m (700-800 m)	The reading distance inside the chip pile is about 20 cm. Data transfer from the sensor inside the pile with a cable or a rod to the Seemoto -electronics unit.	Data transfer from a base station directly to a web service (Private Cloud service). Web service enables real-time monitoring of temperature and transports for instance in hospital, medical and food transportations. Automatic alarm -function, should circumstances change.
Smart Tag (Tre Lab)	Measurement data to the base station with Bluetooth Smart technology.	2,4 Ghz	Reading distance in open space hundreds of metres	-	The base station transmits data between the smart tags and the cloud (Cloud Service + external API).
Smartrac (RFID)	Measurement data from the sensor is transferred to the RFID-device according to the ISO 18000-6 UHF protocol	840 Mhz	Several meters (ten)	Reading distance inside the chip pile (moisture 30-50 %) 1 meter (have to be tested).	-
Haytech (Sensirion SKT25)	The measurement data from the sensor wirelessly to the base station	433 Mhz	Reading distance in open space hundreds of metres	Reading distance inside the chip pile 2-4 meters.	Data is transferred automatically to the cloud. Real-time monitoring possible via a secure network connection.
Sensire (HTS70-20)	The measurement data from the sensor wirelessly to the base station	868 Mhz	Reading distance in open space hundreds of metres	Reading distance inside the chip pile 1 meter (estimate).	Wireless GSM data transfer / communication

Conclusions - Humidity and temperature sensors

- Temperature sensors
  - Temperature measurements are working well and there are several different applications on the market.
  - Allow the detection of overheating of chip piles.
  - The temperature effect on the quality of raw materials requires further experiments.

- Humidity sensors
  - The sensors measure air humidity, not moisture of the material.
  - Some of the sensors are under development.
  - Moisture estimation is successful, if the material is a rather dry (for ex. hay or straw).
  - Moisture estimation does not work well with wet materials
    (wood chips with humidity approx. > 30 %).

Conclusions – Data transfer technologies

- Wireless communication technologies from the sensor to the base station
  - The biggest challenge for data transmission is wireless transmission from pile to the base station, because the signal has to pass an energy material several meters.
  - The inductive (magnetic) data transfer method works very well and permeability is the best – when using the method an antenna must be installed under the pile before building up the chip pile storage. The method is used, for example, in the mining industry and it is suitable for the use in terminals and storage fields at the mill.
  - In radio wave technologies, the highest transmittance is 434 and 868 MHz frequency bands. In addition, these types of sensor solutions provide very good component support due to the large number of applications.
  - IR technology is not usable, because it requires a signal path in open space.
  - Permeability of RFID technology inside the pile has to be tested.

- Data transfer from measuring system to cloud services
  - Wireless GSM data transfer from the base station to the cloud works well, provided that we are inside the GSM network coverage area.
  - Because of dead spots / Blind spots it is required that the data is stored also to the base stations and transmitted forward then again, when you are inside the coverage area.
  - There are a number of service providers.

Expert interviews

- Haytech Oy & VTT **Nadine Pesonen**
- Karelia AMK, **Markus Hirvonen, Ville Kuittinen, Anssi Kokkonen**
- MeshWorks Wireless Oy (Seemoto), **Marko Kyrölä & Okko Riihimäki**
- Measurepolis, **Jouni Tornberg, Petri Österberg**
- Santa Margarita Oy, **Juhani Lehtola**
- Sensire Oy, **Pekka Niskasaari**
- Smartrac Oy (DogBone), **Lauri Hyytinen**
- Treelab Oy, **Ismo Laitinen**
- VTT Technical Research Centre of Finland – Espoo, Finland **Timo Varpula**
- VTT – Kajaani (CEMIS), **Timo Lehikoinen**

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Trelab Oy (http://www.trelab.fi/)

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