Biodegradable sensor nodes

Zero ecological impact nodes for wireless sensor networks

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1 Introduction

In the past years, big data (large amounts of data collected and analysed by autonomous systems) has gained in popularity among business leaders, governments and entrepreneurs. This has given rise to or is caused by (it’s a bit of a chicken egg situation) DDDM, or Data Driven Decision Making. Its problem is however, some things are not measurable yet. Because there is no scale, because there are no sensors, or because humans can’t reach the correct measuring sites. This lack of data prevents us from having a holistic analysis, and thus a proper decision that is not best on paper, but the best solution in the context of its surroundings.

This projects aim is to close one gap in data collection in the most positive way possible. The gap in data from fragile ecosystems using biodegradable, zero ecological impact sensor nodes. These fragile locations can not all be quantified by traditional measuring equipment as these systems always have to be removed after use. This is not always an option. The solution this project proposes is the fabrication of biodegradable sensor nodes that do not need to be retrieved. While redesigning electronics, the opportunity to embed ecological considerations into the design should not be wasted.

The designing of this solution will be done in three stages. First stage will be understanding the problem: What is biodegradable/ zero ecological impact, What is wrong with current electronics (in terms of biodegradability/zero impact), What is a sensor node, What exist to solve this (state of the art) and who should use the sensor node. The second part will be designing a general solution and answering the question, how can this be made. This will be done based on the previous findings The third part will be a final design and analysis of the solution with experts and users. At this stage a proof of concept will be made and tested. This answers the question, could it work both in terms of technical functioning and in terms of market opening.

2 Analysis

The issue with current sensing technology lies in the fact that both the construction and decay have strong environmental impact. This mainly comes from the electrical origins of the sensor nodes. This problem, leads to a second problem, the retrieval issue. This means that for every use of sensor nodes a plan needs to exist about retrieving the nodes, or accept the risk of pollution due to decaying nodes. This leads to some environments being unresearchable, as sensors can not be retrieved, but pollution is not an option.

The redesign of sensor nodes to solve the above problem, gives the opportunity to reduce the problem of human environmental impact, by designing the new sensor nodes in a more environmentally friendly way. This also paves the way for making biodegradable electronics for other purposes while generating a minimal environmental impact.

2.1 Plan

The main research goal is to find a way or method, to construct a zero or low ecological impact, biodegradable sensor node. The plan for finding this is twofold. On the one hand a basic principle will be searched to construct a node and on the other hand, usability questions will be addressed. This will be achieved by answering the sub questions; what already exists in terms of biodegradable electronics and are current electronics not, what are possible users and what do these users want from a system, how can a sensor node be made in terms of its components, can this be proven, and lastly, what has been achieved and what still needs to be done.

These questions will be answered by means of a state of the art analysis, an analysis of the current electronics, a brainstorm with peers followed by interviews with the user groups, a design for a biodegradable sensor node, another user test to affirm the interviews and their incorporation into the design, a proof of concept study on the conductance method and lastly an evaluation and a future work roadmap.

2.2 Zero impact and definitions

One analysis method for assessing environmental impact is the zero ecological impact definition used in construction [2]. This will not be used as a prime metric but as a reference for the ultimate goal of designing a functional sensor node that is mainly biodegradable. This definition is specific for buildings but in many ways it can be used for electronics. Some factors like land use and water use however are not related to electronics manufacturing. It has to be mentioned that these factors are relevant for the other supply chain links. The metrics of zero energy and as little as possible materials and predominantly reusable materials is very relevant in this last supply chain link. This impact will not be assed in current electronics but only in proposed alternatives. The reason for this is the complexity of current supply chains and the secrecy with which they are shrouded.

Another definition can be made to assess the current state however. In this study that is not releasing chemicals into the environment that have a negative effect on flora and fauna in the devices immediate vicinity or farther away. The dutch government has made a list of chemicals that are harmful to their surrounding when released the “prioritaire stoffen lijst” [1]. This list will be used when considering certain chemicals in the proposed and existing electrical systems.

For the non polluting definition there are three methods to make sure it is abided by. The first method is making sure there are no harmful substances in the system, thus they can’t possibly escape and therefore not pollute. The second option is making sure there is no way the substances can enter the environment. And lastly and option is to make sure the systems is not in a pollutable environment. Translating this to objects we get an object that breaks apart, but into non harmful substances, an object that does not break apart and a system that takes itself out of the pollutable environment. This last option could be a sensor node on a drone that flies to a certain place when it almost breaks apart. This does not fundamentally solve the issue of pollution as, non pollutable locations are virtually non existent. The non deteriorating system has a different problem. The pace at which electronics improve is fast, making almost indefinitely stable systems causes the world to have a higher influx of new electronics than old ones vanishing. This type of problem already exists with nuclear waste but also in electronics it already happens with fast product cycles and short life times. The result is called e-waste. The first option, in the way of biodegradable electronics solves all these issues with little foreseeable drawbacks. Also, this technology would be better in terms of ecological impact as the degradation can have a positive environmental impact instead of a negative one.

The definition of a sensor node is a unit within a web of sensor nodes that each measure certain parameters and communicate these across the web of sensors to be read out on a central point [3]. Other sources state that a sensor node architecture is like depicted in diagram 2.1

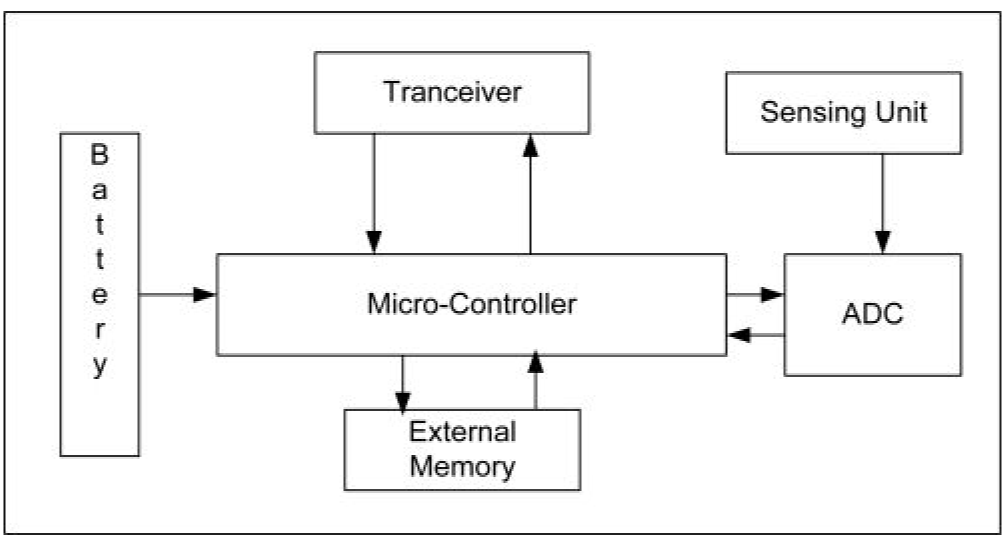

Diagram 2.1 sensor node architecture [4]

2.3 Current state

The definition in diagram 2.1 is a little vague in parts like, ‘transceiver’ and can be clarified more into elements like: Microcontroller, Radio, Flash memory, Power Controllers, Lithium Polymer (LiPO) battery charger. These things are build out of the standard electronic components: inductors, capacitors, resistors, transistors, integrated circuits, batteries and pcb’s (printed circuit boards). These components contain harmful elements for the environment the sensor node is in when it decays. To find out what components are exactly harmful and how this can be prevented, every component will be checked for its chemical components and whether these are on the aforementioned list of dangerous chemicals.

The electronic components that will be evaluated on chemical toxicity are: capacitors, inductors, resistors, integrated circuit packages, batteries and printed circuit boards. These are chosen because most electronic devices are build up with these components. This means that the analysis of these components will represent qualitative toxicity results for all types of circuits. These components will also be assessed in terms of biodegradability below.

Coating

Because most electronic components are cased in plastics or epoxy [5], these sealants will be discussed separately from the other components. No poly-carbon compound has been found on the list deeming it as safe for the environment in terms of toxicity, as plastics are polycarbonates in general. There are however plastics that are not only safe for the environment but also biodegradable. These are bioplastics. These bioplastics solve the problem of non-degrading plastics, which prevents effects like the plastic soup.

Alternative coatings are found in the form of lacquer. This is usually polyurethane, which is not listed as a toxic material. However, as this is a synthetic polymer, its biodegradability is questionable. Some types are slightly biodegradable, others are not [6]. Therefore no clear line can be drawn on whether a general polyurethane is biodegradable or not.

Capacitors

Capacitors are generally available in multiple types. The basic types are Ceramic, film and electrolytic capacitors.There are more types but most are a combination of the previous archetypes.

Ceramic capacitors are made using alternating layers of metal or conducting material and a ceramic material as deëlectric component [7]. This ceramic is a mixture of finely ground conductive and non conductive material, usually this is metal and a metal oxide. The ratio between these two materials in the ceramic deëlectric determines the capacitance. The metal embedded in the ceramic and the conductive metal used for the capacitor are the only materials that can possibly be found on the list. Therefore if a metal not on the list its use would inherently be acceptable according to the toxicity definition.

Film Capacitors are different from ceramic capacitors in that they use a plastic foil as deëlectric material [8]. This allows them to be stretched, rolled up and wound into a tight package. The only two materials used are a plastic and a metallic compound which is attached to the plastic foil. Similar to the above ceramic capacitor the metal is the crucial part of the system. Whether or not the metal is on the list, determines the suitability of the capacitor.

Electrolytic capacitors are based on three components, a metal anode, an oxidized cathode and an electrolyte in the middle. There are three types of anode cathode and three types of electrolyte combinations classifiable. These categories are aluminum, aluminum oxide combination, tantalum, tantalum pentoxide combination and the niobium niobium pentoxide combination. For the electrolytes the categories are generally, liquid electrolytes, solid manganese oxide and solid conductive polymers [9]. The electrodes are not listed and will therefore again be seen as acceptable. The liquid electrolytes however are too unspecific to judge, therefore it will be assumed that there are electrolytes that are not on the list.

Inductors

Inductors consist of a coiled piece of wire around an iron like or plastic core [10]. These simple components are toxic based on the wires being copper. Copper (CAS number 7440-50-8) and copper bonds are under the same number entered on the priority elements list [1]. Iron and ferrite are not on this list and therefore not considered dangerous.

Resistors

Resistors have different types that are used in the industry. The different types are: wire wound, carbon composite, carbon film, metal film, metal oxide film and foil. Wire wound resistors are made from resistive wire which is often formed from a nickel chromium alloy [11]. Chrome is an entered substance together with chrome bonded materials at CAS-number 7440-47-3 [1].

Carbon composite and carbon film resistors are both mainly made of carbon, carbon composite however is mixed with a ceramic filler to increase the resistance per unit of length while the carbon film resistor consists of pure carbon wound up and cut with a spiral path to increase resistance [11]. Carbon in its pure form or mixed with anything but sulfur is not present on the priority list and therefore considered safe in this study.

Metal film and metal oxide film are similar to each other in that they both have a metal that is altered to have a higher resistance, in metal oxide film this is oxidation, in metal film this is a spiral pattern like in the carbon film resistors. These resistors can be deemed safe based on the metal used. Ceramic materials are not entered on the list.

The last type is the foil type resistor. These resistors are made from a metal film, cemented on a ceramic substrate [11]. Again it can be said that this is an acceptable resistor given a metal or metal oxide, is not on the list.

Integrated circuit packages

These packages form the basis of modern electronics with precision laser trimmed components inside and conductive pins or pads to connect the package to the rest of the circuit.

In terms of degradability the problem arises in the doping of the silicon wafers. These dopings often times consist of phosphorus, arsenic, boron or gallium [12]. Arsenic alone is already known to be very toxic as well as all other mentioned dopings. It is however important to understand that integrated circuits are just regular circuits on a tiny scale. Therefore a transistor is the main component that is not in the other types of components, to be more specific the n and p doping is the most basic part of this. These components are also used for diodes for example. The biodegradable, and safe, alternative could therefore be found in materials that show the same electrically biased behaviour as p or n doped materials, or behave like semiconductors in general. Before the time of dopings, crystals and vacuum tubes were used to achieve these results. It is expected that these types of devices will also provide biodegradable alternatives that are non toxic.

Batteries

Batteries, or chemical power cells are based on the principle of the redox reaction in which two separate conjunced, chemical reactions exist by exchanging electrons while maintaining charge via an ion connection. An electrolyte is added between the cathode and anode to help ion flow through the separator [13]. Commonly used nowadays is the lithium polymer (Lipo) rechargeable battery and the lithium ion cell. There are many types of lithium batteries but most have in common that materials are on the list of dangerous substances [1]. For example only lithium titanate with manganese was found that is not on the list. This however is still not biodegradable.

PCBs

Printed circuit boards or pcbs are usually build from a fiberglass reinforced epoxy mixture. Most suppliers will also have epoxy resin as main component in their listing as was found on alibaba.com [14]. Depending on the used epoxy, this material is not on the priority list. The material is however not biodegradable. Here the same issues arise as with conventional plastics like discussed above under ‘coating’. Additionally the use of acids is unavoidable to form the conductive paths that make up a pcb. This process is roughly analogous to carving a statue, a bulk material is made and reduced via in this case chemical instead of mechanical means, into the desired form.

Conductors

Conductors in general are metals. Some of these, like copper and lead are on the list, but materials like silver and gold are not. This generally means that some metals are acceptable to use in terms of toxicity, but as they are metals, they are by definition not renewable. This leads to them having a negative environmental impact. Additionally metals are not biodegradable, some are biocompatible, some are even beneficial to organisms in small doses, but biodegradability is not interchangeable with biocompatibility.

Conclusion

In conclusion as can be seen in table 2.1, no component is biodegradable but some are safe. As the title of this study is, biodegradable sensor nodes, no component can be used and everything has to be remodeled to be biodegradable.

Table 2.1

Component	**Safe**	**Biodegradable**
Plastics	Yes	No (although some examples exist that are, most are not)
Ceramic capacitor	Yes (given the right metal)	No
Film capacitor	Yes (given the right metal)	No
Electrolytic capacitor	Yes (given the right electrolyte and metal)	No
Inductor	Yes (given the right metal)	No
Wire wound resistor	No	No
Carbon composite resistor	Yes	No
Carbon film resistor	Yes	Yes (given no plastic shielding and no metal connectors)
Metal film resistor	Yes (given the right metal)	No
Metal oxide film resistor	Yes (given the right metal)	No
Foil resistor	Yes (given the right metal)	No
Integrated circuits (p/n doped)	No	No

Battery (lithium based)	No	No
PCB	Yes	No
Conductors	Yes (given the right metal)	No

2.4 State of the art

The state of the art in this research focuses on biodegradable electronics. This means that innovative ways of using conventional electronics are disregarded.

Organic electronics

Organic electronics are an interesting field of research because it encapsulates so many different scientific disciplines. Since 2000 the journal ‘Organic electronics’ has existed. This has already featured papers on organic transistors [15], organic LEDs (OLED) [16] and organic solar cells [17]. There are currently 59 volumes of this journal. Most components are however are only fabricatable with high tech equipment. The main focus within the journal seems to be on organic leds, photo sensors and photovoltaic devices. It is expected that most information on component materials can be found in this journal.

Organic electronics is also a field being researched by companies. It is however difficult to say what companies and labs are involved. One day a lab was found in germany but the next day that lab no longer had any information about organic electronics on their website, this suggests a great deal of secrecy.

Organic circuit device patent

Integrated circuits, mainly semiconductor components like transistors are found too. They are often described as OFET (organic field effect transistors). It should however be noted that there is a 2012 patent on biodegradable electronics resembling integrated circuits, filled by MIT under “Biodegradable Electronic Devices US 20120223293 A1” [18]. This patent also describes crudely how certain electrical elements can be made using biodegradable components. This again suggests that the hurdles of biodegradable electronics do not lie in the knowledge about alternatives, but are due to other reasons.

Nano-net journal

Additionally the use of fully organic devices is researched in many studies listed in the nano-net journal [19]. The focus of this study is captured in the introduction of the fourth gatherings journal. “The major focus of Nano-Net remains related to discovering and revealing a new exciting domain emerging at the cutting-edge overlap of two well-established and highly innovative disciplines, which are information and communication science and nano-technologies. ”. This last field however is completely out of reach for this investigation due to being too far out of expertise for the writer. This means that the described methods could be more suitable, but are not executable by the writer.

3d printing circuits

3d printing circuits is mostly a field being researched with classical electronics. There are however also isolated examples where the 3d printed electronics are biodegradable [20]. The paper on biodegradable 3d printed electronics, focuses on the manufacturing instead of the materials, it therefore provides no answers to the questions at hand. These questions are the search for alternative materials. This method of 3d printing electronics using biodegradable polymers could however be an excellent method for mass producing unique biodegradable sensor nodes, although a slow one. The paper however does not help in finding materials to do so.

Biodegradable plastics

Since biodegradable electronics decay, which is their goal, they need to be shielded from premature degradation. This can be done by making cases from biodegradable plastic. The thickness and exact material can determine how long it takes for the components to be exposed to the elements that degrade them. PLA seems to be a good material for this as it is made up of renewables like corn, takes a long time to degrade and can degrade in water [21].

Conducting ink

Conducting ink, usually containing metal particles, has also been made in pure carbon variants. While carbon is not biodegradable it is completely harmless to the environment when diluted in water or adsorbed in soil. Additionally, the carbon used in these inks can theoretically be produced with renewable resources. This conducting ink has reached resistances below 30 Ω/cm^2 [22]. This ink could be used as an alternative for the conventional copper connection lines. Additionally, different resistances can be achieved by changing the carbon content of the ink, making tunable resistances again possible.

Silk

Silk, a polypeptide structure (silk as remodeled fibers, not as fabric known from the clothing industry) , is currently used in biological implant applications as substrate for electronics. This enables electronics to be mounted on the surface of for example brain tissue without damaging the brain or electronics, as the silk is reabsorbed in the body [23]. This could be used instead of current pcbs to decrease their influence in the biodegradation of the electronics on top. However, while silk is renewable, the price of pure organic silk lies higher than that of other biodegradable substrates.

Carbon supercapacitor

Supercapacitors are made, unlike most regular capacitors with 4 instead of 3 components. Regular capacitors consist of two plates with a dielectric in between. The electrostatic charge on the plates is prevented from short circuiting by the dielectric. A super capacitor has an additional electrolyte that ‘connects’ the two current collectors. The two current collectors have to be shielded to prevent chemical reactions, this is often done with carbon compounds. This makes it possible to put a charge on the current collectors without the current collector reacting and creating a chemical cell. Now however a charge creates a double layer capacitor with the electrolyte. This has been tested by many people among which a battery manufacturer with a youtube channel who has achieved promising results with his biodegradable all carbon supercapacitor designs [24]. These results are believed to make a similar supercapacitor array suitable as power supply.

Biodegradable implanted sensors

From ‘Towards biodegradable wireless implants’, it can be learned that in the medical world there are defined, “biocompatible metals (Mg, Mg alloy, Fe, Fe alloys) and biodegradable conductive polymer composites (polycaprolactone–polypyrrole, polylactide–polypyrrole).” [25]. These elements can be used to engineer alternatives for the conventional electronics since, if something can safely degrade in the human body it should pose little problem degrading outside the human body. Regarding reliability, manufacturing processes and ecological impact of these two, the use of metals has a negative environmental impact as it is non renewable, where plant based materials have a positive impact. This research focuses on a biodegradable sensor node that is as close to zero ecological impact as possible. This would probably be a simpler and renewable device. These aspects make them unsuitable for biomedical use.

P-LIT graphene production

A method of inducing graphene formations has been researched at Rice university.[26] The method researched was laser induced graphene using an industrial laser cutter under argon atmosphere. The test was conducted using a 75W laser cutter at multiple power levels. The results were that above 50% power level graphene was formed in such quantities that the resulting surface was conductive with a resistance around 10 Ωs per square centimeter. The Co2 laser was measured to be 6.3W at this 50% power level at 10.6 μm wavelength (This is laser power, not electrical power). At power levels lower than 50% graphene still formed but in much lower quantities resulting in higher resistances. This is very useful in actualizing computer designed circuits as any resistance can be ‘constructed’ in the same process step by dialing down the etching power. The best etching power was 70%, this was named as the ideal for forming graphene. This method also allows for the use of plant based materials to form the backbone of the electronic devices, reducing overall ecological impact as compared to non organic resources. This ticks the box of both biodegradability as well as being positive on the zero ecological impact scale and being constructed mainly of renewable resources. This makes the P-LIT method a great candidate for further testing.

Biological sensors

Multiple types of biological sensors are being researched among which the aforementioned pv cells and similar light sensors. The department advanced research projects agency (DARPA) however also runs a project on using organisms as sensors under the biological technologies office. This includes monitoring sea creatures with a small amount of sensors to cover a large amount of sea in the surveillance sense of the word [27]. Another project however focuses on using genetically modified plant life to indicate soil and air pollution [28]. These advancements indicate that research into biological sensors is being done and is a study on it’s own. Therefore it will not be researched further in this study other than what is mentioned here.

2.5 user requirements for a biodegradable sensor node

The main question of this paragraph is to investigate the influence and prefered influence of users in the design process. The role that stakeholders and their requirements should have in the design process will be evaluated by analysing who the stakeholders are and what they would use the system for. These uses lead to requirements for every stakeholder group. The requirements are first hypothetical and will later by means of interviews be verified or rejected. This is done to get the most general input in the earliest stages of the design process.

Stakeholders

The stakeholder groups were based on a brainstorm session with peers. This session was mainly focused on correcting personal bias, and closing gaps in knowledge about possible groups. As a result the identified stakeholder groups of biodegradable sensor nodes are mostly researchers in ecological fields, civil engineering contractors and researchers, farmers, the DIY community and companies with large outdoor facilities, like Rijkswaterstaat. These are the main stakeholders because these groups can either use biodegradable sensor nodes for their own research, innovative monitoring of systems, structures and locations, or add to its value by innovation on the base system. These users are among many possible users but should be seen as examples. They originate from a brainstorm session with peers. As can be seen there are three categories they can be divided in. Researchers, surveillers and innovators. These groups will be analysed further and people from each group will be found and interviewed.

Researchers

Research is using the biodegradable system as a platform for scientific research. A sensor is interfaced with the system to monitor natural or biological phenomenon. The accuracy probably needs to be high for systems like these, while it should also be simple to use. These are just assumptions right now.

The stakeholders for this topic are earth scientist, biology scientists, Marine biologists and similar types of scientists. Some companies might have an interest in the same applications but for the sake of simplicity the before mentioned scientists are the primary stakeholders. The scientist interviewed were biology oriented. Sensors are currently being used in the form of camera traps, gps tags and soil probes according to an interviewee. Biodegradable sensors and sensor nodes could be very beneficial for research in delicate nature reserves as the team only has to enter the area once to plant a sensor and never again has to go near it. For gps tags this could also be beneficial as recovering these tags from wild animals can be a pain. It was said that this technology would be beneficial to much fieldwork if the device is accessible remotely. A lifespan would be related to the application, a gps tag should live at least as long as the animal while a soil sensor can stay operational as little as a year. The main problem would be the communication range of the node for this group. This range should be very large.

Surveilers

Monitoring has two main branches. Conventional monitoring and next-gen monitoring. Conventional monitoring is an electrical version of existing monitoring methods like for example water level poles being replaced with a sensor. The next-gen type of monitoring is an Internet Of Things (IOT) setup. This means that many sensors collect data that was previously inaccessible or not relevant, and parse this data to an interface. The application for this could be in dyke monitoring where a large number of sensors monitor the dyke where previously people had to walk on it and visually check it. In these types of applications measurement resolution is less important than reliability, you don't need to know how many 1000s of millimeters are rubbed off of the tire, but you do want to be sure that the measurement is correct. Additionally cost is an important role for large scale implementation. This again is just speculation.

The stakeholders for this topic are city councils (smart cities), Rijkswaterstaat, large outdoor facilities, civil engineering contractors and farmers. These groups can benefit from both types of monitoring in their professional environment. From interviews it is observed that the measurement resolution is dependant on the intended application. But the possibility of developing biodegradable sensors that are less dense in resolution is acceptable if the application allows it. A working life of 15 years may be long, but about the time a sensor node should be operational. Cost is more important than operating time however. Embedding sensor nodes in buildings is a possible application, but use in the foreseeable future will be very limited. In this case the sensor lifespan should be equal to the lifespan of what it was embedded in. These were the main points given by interviewees that are stakeholders of the monitoring branch. Only three people were interviewed, so no definitive conclusions can be made, but the points will be taken as guidelines.

Innovators

Innovation on the biodegradable sensor node is expanding its capabilities , making it smaller or cheaper. This will probably be done by other scientists, but it is preferable if the DIY community helps in this stage. This is to force the hand of corporations into making even better versions for the large scale applications and consumers becoming engaged (becoming pro-sumers) in less polluting electronics. To encourage this user engagement, the product needs first and foremost to be understandable. If the product is understandable the barrier of entry is lowered and more consumers are likely to join in the research.

The stakeholders for this part are mainly the DIY community but also researchers and companies. The main focus however will be the DIY community because of the limited resources they possess. After questioning some possible DIY innovators they told that the main hurdles would indeed be in understandability. When the system has no documentation and is illogical or very complicated they would not want to work on it. The system should however also be customizable, the sentence "if you can't open it, you don't own it" was said. The point is that the system should not be completely shut but customizable in its core functions with simple tools. Flexibility was also a request, the system should be able to handle changes that are made in it. For example if the system only communicates on one band some features can not be implemented making the system harder to work with. The system should be cheap, but also available. This means that the system should be purchasable at larger retailers or online platforms, for a fair price. It was also mentioned that the system should be open source to encourage community adaptation of the system. This increases the amount of people willing to work on it. Like in the above part only three people were interviewed.

Requirements

In the end the three groups have the following requirements. First of all the scientist group. This group mainly benefits from the biodegradable aspect of the system but also needs a very large range of communication. Incorporation of existing accurate sensors is a benefit to use the node in more situations. Secondly the group of surveillers wanted a cheap system, with a measuring resolution appropriate for the goal they want to achieve. Most importantly is the reliability of the measured points. Lastly it was said that a node should last for about 15 years. Lastly the DIY people have asked for a simple, hackable device that is flexible in capabilities, cheap and easily available.

In the end this boils down to a simple open system that is as cheap as possible while maintaining good measuring capabilities. Therefore the sensors should be separately attachable to cater for every group as well as possible. The system should also be modifiable and last approximately 15 years.

3 Design of a biodegradable sensor node

3.1 Design of a biodegradable sensor node

Black box design

The black box design phase is useful for identifying inputs, outputs, information and energy streams. In the case of a wireless sensor node this is the sensor data based on the sensor environment related to the sensitivity of the sensor, the wireless output of the node itself and the energy required by the device. In a biodegradable device the main process all devices have in common is the decay into 'compost' due to interactions with microorganism. The combination of these two things is depicted in image 3.1.1 as the black box view of a biodegradable sensor node.

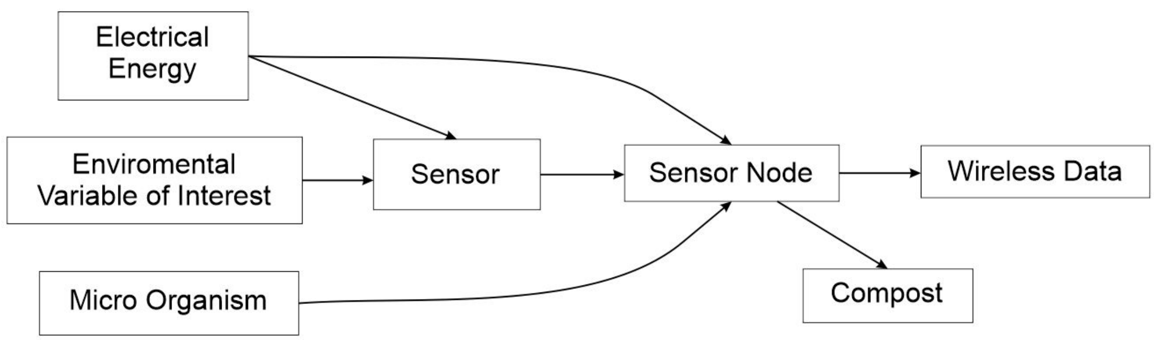

Image 3.1.1 Black box view of a biodegradable sensor node

To further elaborate on image 3.1.1 it is important to remember that this thesis sees the sensor of a sensor node as a seperate device outside of its scope. Further, left of the Sensor Node block are all the assumed given inputs. On the right are the outputs of the device. Note that Wireless data is supposed to be a standard output over the time it takes for the device to become compost. Lastly, the states are not of interest, as in all black box designs the transitions (arrows) are of interest. Electrical energy is posed as a given but will be expanded on in the coming chapters as an independent storage device device.

The Sensor block is also assumed a given, but it is important to further define what sensor type is assumed to be used, as there are multiple fundamentally different sensing methods. First of all the sensor is assumed to be analog and not digital, as the simplest possible sensor node is also analog. Furthermore a digital sensor is more likely to contain on board electronics containing the pollutants mentioned in chapter 2.2 and deemed dangerous by Dutch Environmental Assessment Agency whose list is the basis for the assumptions of safety made in chapter 2.2.

Component layer design

Based on the black box design made in the previous paragraph the components of such a sensor node can be clarified as separate, communicating, smaller black boxes. Basically there are three types of analog sensors. Resistive sensors, capacitive sensors and inductive sensors. Due to the fourier theorem we can approximate a DC signal as a sum of AC signals. Because of this assumption it can be reasoned that there are three ways to change a real signal. The signal can be altered in amplitude, frequency and phase. These signal changes can be made by a changing electrical component, a sensor of the resistive, capacitive or inductive type. Therefore these three types are the archetypes for analog sensors and sensing.

The resistive type is the simplest to describe as the change in the sensor can be measured with a DC power input over a voltage divider circuit. This is encapsulated in the resistive sensor block. The output is a DC signal that can be turned into an AC signal via a frequency modulator and sent via a transmitter as an FM signal. This is shown in image 3.1.2 as a block diagram on the functional layer.

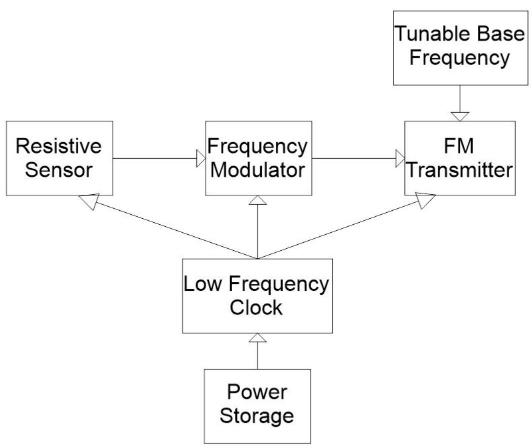

Image 3.1.2 Component design of a sensor node for a resistive sensor

The Low Frequency clock is intended to limit operating time, to save as much power as possible. It does this by acting as a power gatekeeper, switching the supply rail of it’s higher components. This is highly dependent on application but can usually be assumed to be in the order of one or more measurements per hour.

The tunable base frequency is more a property of the global device than a seperate device. Its main purpose is to make the global node identifiable based on the communication frequency. This allows a region to contain more analog sensor nodes while keeping them simple and unique, so that different measurements can be distinguished from each other.

Sensors based on other measuring methods, frequency related measuring or capacitive measuring need a different approach as the frequency information would get lost if passed through the frequency modulator. A solution for this can be either an amplitude modulator and an AM transmitter or accepting the loss of data and using a comparator to set a threshold value at which broadcasting changes or starts. This last solution is basically changing the sensor node from a sensor node network to an alarm network.

The reason to focus on resistive sensing is purely due to a time constraint on this research. Resistive sensing is the simplest method to design a sensor node for and allows the author to delve deeper into the node manufacturing.

Electrical component design

The blocks above are related to general electronic components. These can be made biodegradable by combining the information found in chapter 2. The method of manufacturing these components will be addressed in the next paragraph. Here the focus lies on listing the general components that are needed to make a sensor node like described above.

The black boxes will be treated like seperate units and no fitting of the components values will be done. This choice is made because there are too many unknowns about the system at this point in research, and the overall case is deemed more important than the electrical soundness of the specific design. This meaning that it is more important to know what components are needed instead of what value each component should have. The blocks that will be discussed are the sensor interface, frequency modulator, fm transmitter, tunable base frequency, low frequency clock and power storage.

The sensor interface is the electronic interface where a conventional resistive sensor can be connected to be interpreted by the system. A good way to accurately read resistive sensors is by using a wheatstone-bridge setup. This setup allows for relative measuring and partially compensates for environmental factors like temperature while also amplifying small signals. Some examples can be seen in Image 3.1.3. The setup in (A) is prefered as it allows more components to be integrated into the biodegradable setup and away from the conventional electronics. Secondly the setup in (A) allows for better integration into the circuit as only two wires have to be run out of the circuit assembly to connect conventional sensors.

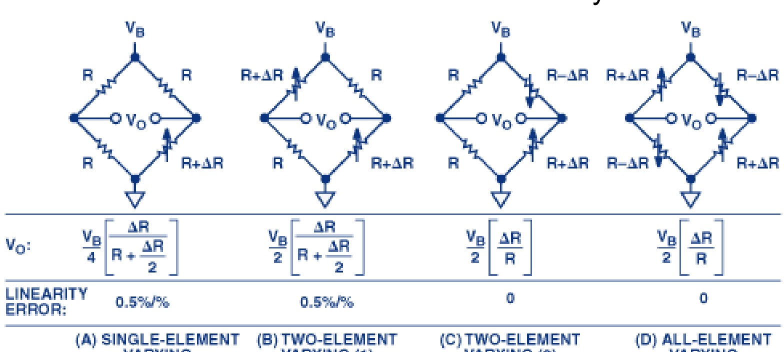

Image 3.1.3 wheatstone bridge examples [29].

The frequency modulator has two tasks, first it is supposed to transform the dc signal into an ac frequency and secondly it is supposed to transform the dc sensor signal to an ac signal in such a way that it can be sent by the fm transmitter. The LM331 integrated circuit does this [30], but is not biodegradable. Therefore an alternative has to be found. One option would be to ‘break apart’ the IC and recreate it with biodegradable means, but the system requires two Op-amps which in turn would have to be made biodegradable again. This would make the overall circuit so complex that it would be unrealistic to produce. A voltage controlled oscillator could however solve this complexity issue. The issue then would become the availability of biodegradable diodes. A diode is however not needed in a clapp oscillator. Additionally the frequency band that the oscillator used is tunable by changing the values of the R3, C1 and C2 components.

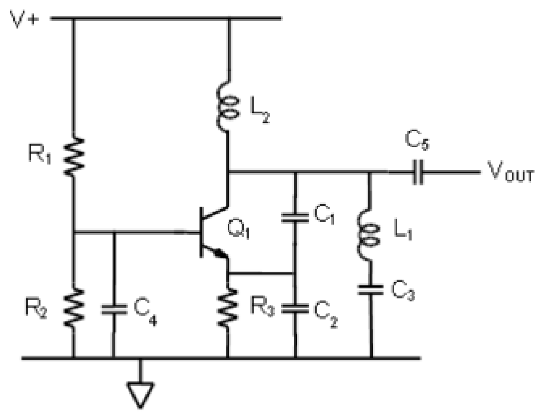

Image 3.1.4 Clapp oscillator, the transistor can be replaced by an OFET [31].

An fm transmitter has been chosen due to their reliable communication. The frequency band of the transmitter has to be chosen so the node can reliably communicate to the hub. The reliability of the communication is based in two factors. Firstly if the signal is received by the hub as it was intended, and secondly whether the sent signals are received. The fact that an fm transmitter is used helps against the first problem, and the second problem can be solved by using the proper frequency bands or locating the hub and nodes in such a way that it is less of a problem. It should however be noted that wireless communication is still an unreliable way of communicating, and this has to be taken into account at the application stage. Usually fm transmitters use transistors but it is possible to use a mosfet instead [32]. It is however not clear whether the setup in image 3.1.4, using a mosfet, or in the intended case O-FET, works with voltages around 3V. It has shown to be functioning with a voltage as low as 18V however [32].

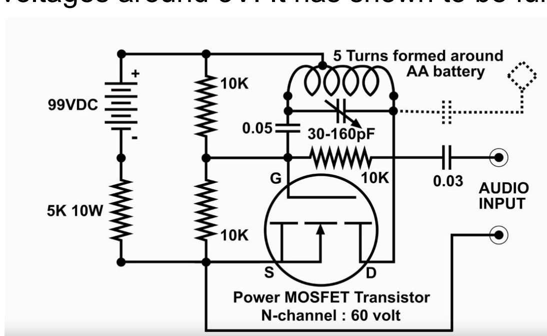

Image 3.1.5 FM transmitter using mosfet, has been shown to work on 18 volts with only changes in component values [32].

A tunable base frequency is necessary to identify different sensor nodes. This is a function that is only necessary when a single sensor hub can receive large numbers of sensor nodes. The theory is that by changing the frequency band of a sensor node the nodes can be grouped to allow a single sensor hub to identify multiple ‘regions’ for, for example monitoring dunes. This allows for more sensors to be used while increasing measurement density instead of only increasing measurement accuracy. The change in base frequency can be achieved by changing the variables in the FM transmitter in specific ways. This is only possible in the manufacturing process as variable components are not foreseeably available.

The low frequency clock is used to switch the system on and off for respectively a short and long time. This makes it so the system can operate for a longer time on a single battery charge. The best circuit for this application would be a low frequency pulse generator. That is connected to the plus voltage lead of the battery with an o-fet to cut off power in the downtime. Three OFETs have to be used for this application in combination with two oscillators. These two oscillators need to have the same extremely low frequency with an offset of just below 180 degrees. The transistors are used to make an AND gate so that the power OFET and the system, is only turned on when both signals are high. This happens in the slight overlap that is determined by the relative phase shift.

Power storage can be solved by using a bank of biodegradable super capacitors and charging them before deployment. An option however would be an all carbon paper battery [33]. A device like that can be made using printing technology, paper and electrolyte. These components are not harmful and can be fully degraded, while having a regular power density. This makes them ideal to interface with the biodegradable electronics while not compromising on cost or function.

3.2 Manufacturing

Component manufacture

The components needed for the electronics described in 3.1 are resistors, capacitors, inductors, conductors and transistors. These will be treated separately in this paragraph.

Resistors can easily be made by using carbon in a non ideal conducting situation. Tests done by the author have indicated that patches of pencil deposit (an 8B derwent pencil was used) have a resistance around 4K Ω per centimeter distance between the measuring points. This leads to the belief that non-ideal e-inks can be used as laser trimmable resistors. Image 3.2.1 shows how this laser trimming can be achieved. The black lines represent conducting paths, the grey square is the deposit of resistive material. The red line represents the laser etched conducting path at the right resistance. The resistor dimensions are supposed to be as close to the needed size as possible, but more than the need value so that this etching process can reduce the resistance very accurately.

Image 3.2.1 laser trimmed resistor

Alternatively the method of laser etching conductive paths can be modified to generate resistive portions in the path. This modifying is done by reducing the laser power of a 75W Co2 laser to under 50% proportional to how resistive the part has to be. This method will be tested further in the next chapter.

Capacitors can be made by using the same method for the conducting material with the addition of connections. This would result in a capacitor made from pinewood with two current collectors on both sides of the wood. This is represented in image 3.2.2C. The brown surface represents the core that is still of wood where the grey area is conducting. The black lines only help represent the shape of the drawn object.

Alternatively capacitors can be made from paper with conducting material painted on both sides of the paper, rolling the paper up and waterproofing it. Then a NaCl solution can be added to make the capacitor function as an electrolytic capacitor. In image 3.2.2A the base material shapes are drawn. On a piece of paper where both sides have been made conductive with connector tabs for each side. The white square above that is the insulating layer to ensure that after rolling the capacitor, the two conductive sides don't touch. The rolled state is represented in Image 3.2.2B.

The manufacturing of a paper battery seems to follow the same method as the method for making a capacitor like described above. Therefore it is assumed that these types of paper capacitors can function as battery when scaled properly.

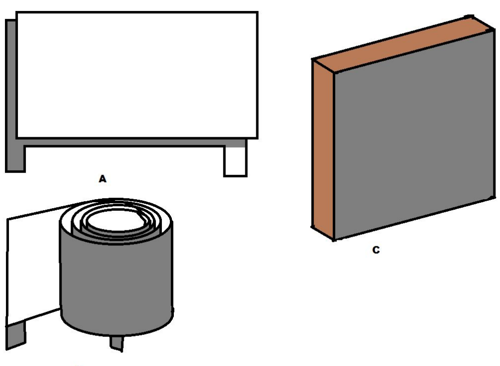

Image 3.2.2 Capacitor types

Inductors can be made by the same method as conductors. A spiral conducting path on a flat diëlectric surface behaves like an inductor if shaped correctly [34]. The method deemed to be most relevant for the planer nature of laser etched conductors, is planar inductors like described by John Capwell. How the path itself is made, will be described in the part about conductors.

Conductors (and inductors similarly) can be made on a plate of pine using the methods described by the Rice university team [26]. It boils down to laser engraving a piece of pine wood under an inert atmosphere (Ar) so the material can not ‘burn’ but forms graphene layers. The laser used was a CO2 laser like commonly found in industrial laser cutters. This enables pre programmed paths and pads to be laser-engraved into the wood. The research also showed that laser power is related to the resistivity of the path. A 75W laser (that was used in the research) at 50% power or higher resulted in a square resistivity around 10 Ωs where 10% laser power, resulted in values higher than 1MΩ. This could be an alternative to the resistive e-ink.

Transistors are more difficult to make and require multiple steps in order to make them. It however boils down to eching a drain, source and gate on a piece of pine and connecting the source and drain with a thin layer of tyrian purple, topped with indigo [23]. Image 3.2.3 illustrates the architecture of such a transistor from a side view. The tyrian purple is not drawn as it is comparatively little and only used to provide a base for the indigo crystals to form the right geometric crystal lattice. The source, drain and gate in grey again illustrate conducting paths engraved in the brown pine wood. The indigo colored square represents the indigo semiconductor.

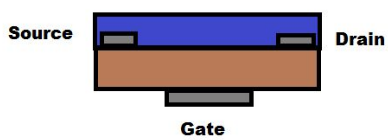

Image 3.2.3 OFET design based on Pine

Small scale manufacture of nodes

The manufacture of all of the before described components requires an industrial laser cutter in an oxygenless environment. The test settings called for a 75W CO2 laser at 10.6µm running at at least 50% power in an argon atmosphere as based on the P-LIG method. The second requirements is the deposition of indigo on tyrian purple, in the same environment. Lastly the turning of pieces of wood to engrave both sides where needed. Additionally it is necessary to coat the device to protect it from premature oxidation.

The device that can do these things is a device like an x-y plotter fitted with a 75W laser (or 40W if 50% of 75W is equal in output to a 40W setup) and a liquid depositor like found in food 3d printers. The atmosphere could be Nitrogen to prevent burning of the wood and simultaneously reducing costs and environmental impact. Nitrogen is like Argon very stable in most environments, but tests have to be conducted to determine whether this is a feasible alternative. The turning of pieces can be achieved by using a simple clamp connected to a stepper motor to prevent disturbing the inert atmosphere.

An x-y plotter with food grade 3d printer capabilities is simply an inkjet printer. Equipping one with a laser setup and closing is off from the air would be sufficient for primary tests given that the reservoir for liquids does not allow the indigo or tyrian purple to oxidise. The most expensive part in this setup would be the laser and the tyrian purple dye. A CO2 laser seems required due to the wavelength, and these only come in tube setups. Therefore a 75W laser tube has to fitted to a simple 3d printer, making this into an infeasible design. If future test however indicate that lower wattage lasers can also create graphene this setup would be prefered due to its low costs and semi portable size.

The other option is fitting a 75W laser cutter with inert atmosphere infrastructure and turnable clamping device, and depositing the indigo mixture in the same inert atmosphere or seperate device with inert atmosphere. This would be the most cost efficient method, but not the most reliable as alignment errors would be frequent.

As delay on the biodegradability, a regular 3d printer can print a case using PLA with a thickness related to the time before the device loses usefulness. This can be scope of operation related, or battery power related.

Lastly the device has to be coated additionally to prevent oxidation of the transistors. Beeswax or other biodegradable waxes seem to be a good option as they turn liquid when heated but solid when cool. Additionally these waxes biodegrade in a short time making them ideal for air proofing without prolonging decay time [35]. A short decay time for this stage is desirable, as the device can be protected by a PLA enclosure that is engineered to last as long as desired. The coating can be done by submerging the finished product in a bath of hot wax. Before encasing in a PLA enclosure.

3.3 specs of nodes

At this point it seems that the nodes can be made using an industrial laser cutter combined with an inkjet printer to deposit the semiconductor material. The nodes can be made with relatively simple electronic circuits and some loose components like the battery and capacitors. These would as described above be manufactured separately, but also be biodegradable.

Costs

The materials needed for the manufacturing process are pure indigo, tyrian purple, beeswax, nitrogen gas and pine veneer or sheets. The tools required to turn these things into usable electronics are a laser cutter of at least 75W, a printer that can print indigo and e-ink in a Nitrogen environment, a turntable clamp and a device for wax baths.

The costs of these materials is quite low. Indigo has been found to be as cheap as two dollars per kilogram of powder [36]. Pine is harder to find because it is not ready to use online. Most types of veneer have glue on the back which can interfere with the etching process. These veneer strips however were in the 10 dollar range and multiple boards, or possibly multilayer boards can be made out of one roll. Nitrogen gas cylinders have been found for 150 euro for 10 liters at 200 Bar. This means that at normal pressure 2000 liters of nitrogen gas can be used. This boils down to a material coat that is depended on the size and production time of the device more than on the components mounted on it.

The only expensive material needed is the tyrian purple. This has been found for a price of $1015 per quarter gram [37]. This enormously increases the cost of OFETs used in the design. For the sake of argument this price will be ignored as other materials could replace the indigo as semiconductor and other materials could be used as cristal seed, reducing the cost to a more reasonable degree.

The tools are more expensive, while still being cheaper than conventional wafer technology. An 80W laser cutter has been found second hand on ebay for 19.000 dollars which indicates that a new one could be as much as 30.000 euros [38]. Modifications would have to be made to allow the machine to create a nitrogen environment. This would further increase the price. A liquid 3d printer has not been found in priced state and seem to be mainly self made by their owners. Regular printers however have been seen for under 100 euros in Mediamarkt. These, or the 3d variety could be modified to work with the special inks used in this project. As modifications have to be made on the printer, a definite price can not be given. A rough estimate would however be a price around 500 to 1000 euros. The turntable clamp can be made using simple material and electronics for as little as roughly 50 euros. The wax bath could be made using a frying machine, given that the chamber would be big enough. The price of a simple frying machine has been found to be 20 euros [39]. This brings the costs of the tools needed to around 32.000 euros to start producing small batches of nodes. Assuming the processes and machines function as described above.

Features

The main feature is of course the biodegradability of the device. However the production process contrary to current electronics manufacturing, allows for low volume manufacturing and even quick prototyping of devices for the same costs as large scale manufacturing would cost. This would allow for specific taylored devices for specific tasks, instead of bulk product multipurpose devices.

A feature proposed by an interviewee was a feedback signal to indicate the device is decaying as it is supposed to. This can be combined with carbon resorption by putting seeds of native plants in the device. When the outer shell breaks the seeds start sprouting and grow above the ground to indicate the device is decaying. Simultaneously the plant can absorb the nutrients provided by the decaying device and absorb carbon from the atmosphere to compensate for the production process. At this point it can’t be assumed that the resorption is equal to the pollution during the production process. However, if renewable electricity is used and the impact of producing the solar panels and windmills (for example) is negated, this could result in zero carbon emissions. This however would have to be confirmed by tests.

Like mentioned in the costs, the manufacturing of these nodes has high fixed costs due to the needed equipment, however if future tests conclude that a laser below 75W can be used to achieve the same results, the costs and form factor would be reduced drastically making it possible to produce nodes in the back of a large van given enough electricity. This makes mobile or onsite production possible.

4 Tests

4.1 user test

For the user test the goal is to validate the assumptions made in designing the system so far, or finding points where the user groups have not been heard well. This means validating the assumptions from chapter two, seeing if they are incorporated well and seeing if that is enough to make an attractive product, or if there are unnoticed demands. This will be done by conducting surveys and analysing the answers of that survey. The exact questions can be found in appendix A. The questions are divided into 4 parts. The first part is the demographic part, the second is a context part, after that a part about the willingness of the participant to use the proposed nodes, and lastly a critical assessment of the practicality.

Demographic

In the demographic part the questions of interest are to which target group the person belongs (makers, scientists, engineers or other) and if there is an age or function divide. The function people have is very indicative for the type of applications people think of and propose in the rest of the questionnaire.

It is possible that a conceptual technology like the one of this study seems highly useful for students but seems too risky for people working in the corresponding workfield. Age could be negatively corresponded to willingness to adapt but is also an indication of experience. Therefore it can indicate on one hand resistance against change, but can on the other hand also indicate that the person is more critical. This can give insight into the other answers given by a person.

Contextual

The contextual questions are aimed at probing the pre-existing knowledge and opinions on the general subject of electronics, biodegradability and sensor nodes of the participant. Here opinions on the subject of economy will also be asked. The level of knowledge of the subject can highly influence scepticism, as well as alternative solutions and understanding of the significance of the problems that caused this research. Skepticism and knowledge of alternatives are presumed to make the person more tempered towards negative in the following questions wheres the understanding of the base problems is presumed to lead to more positive answers. Economy in this case relates to the paths humankind can take towards the future. Some people oppose space colonisation because they find that we made a mess of earth and first have to fix that, instead of destroying extra terrestrial ecosystems. This however would be a source of metals needed for electronics. A person with a belief like that would in general seem to be more in favour of eco friendly, biodegradable technologies in general. This question can also indicate a more general sentiment among people regarding renewables, economy and human interests.

Personal involvement

The third part on personal involvement focus on the opinion of the person filling out the questionnaire regarding use of the proposed technology. Before filling this part out the user will be prompted to watch a video explaining the technology on a basic level. The questions include questions of willingness to experiment and incorporate sensor nodes in their projects. It is often observed that people are highly enthusiastic towards certain concepts but unwilling to act on those concepts. The divide between climate awareness and undertaking action to reduce carbon footprint is an example of this [40]. Unwillingness to use the technology can also come from lack of understanding of the field it stems from, if this is the case it can be assessed based on the information from the context part.

Critical assessment

The last part consists of questions opposite to the previous involvement question. This part is focused on whether people can imagine other using it instead of using it themselves. This part will also contain critical questions on usability.
These questions are aimed at finding out if people are convinced of the possibilities. From this market readiness in terms of market sentiment can be found. If people would either use the technology or see the technology being used by others, it would suggest that the base concept of introducing biodegradability into electrical engineering is a successful concept.

All these metrics combined result in being able to conclude if possible users are satisfied and the requirements are met, or any combination of the two. The requirements were: biodegradable, large range of communication, compatible with existing sensors, measuring resolution, measuring reliability, last for about 15 years, simple, hackable device, flexible in capabilities, cheap, easily available. The collected data from the survey will be anonymous as no user data is recorded apart from an age range, function and self defined user group. The questions that could be used to identify persons (like age and occupation) have been made into broader categories in order to prevent people from being identifiable.

4.2 resistance research

For the proof of concept the relation between etched length, width and laser power will be investigated, to be able to tweak the resistive properties of laser etched elements as discussed in the resistor and conductor part of the previous chapter. If the results from this are clear and usable, a small circuit will be made to illustrate the results.

For this test a chamber will be designed and lasercut to hold the wood that is being treated to ensure that that happens in a nitrogen environment. This chamber will have two hose connections for in and outflow, and consist of circular disks that are separated by rubber seals and bolted together. This gives the possibility of adjusting the height of the internal chamber as desired. The assumptions made for this design are a focal distance of at least 2.5 inch on the lasercutter, a laser power of at least 75W and a nitrogen atmosphere in the cutting area as a result of nitrogen inflow through the inflow port . It is also assumed that a pressure valve is present on the inflow line.

Due to budget constraints the needed ZiSi glass used will be only 20 mm in diameter of which only 12mm can be used due to the designed clamping mechanism as visible in Figure 4.2.1 as the yellow block. This glass is needed as it acts as a window for the laser while keeping the chamber pressurized. Figure 4.2.1 further depicts the chamber design, where the black spots represent rubber o-rings of 56.87mm inside diameter (the larger ones) and 14mm (the smaller one) and 1.78mm tube diameter. The brown spots are wooden and the light blue parts are 6mm thick acrylic plates. The grey parts are m6, 35mm high bolts secured with m6 wing nuts and washers. Additionally two registering screws have been added to fixate the material inside the chamber. This was done after preliminary tests and is therefore not shown in the graph. The screws are roughly 30 mm long m4 bolts. Additionally a base plate with registering slots and scale was made for the pressure chamber to be put on. This was intended to ease the alignment process and is depicted in brown.

The internal volume is about 25mL. The nitrogen will be pumped in at variable pressures, the flow should be at least 3.6L per hour or 0.06L per minute (60ml/minute) in order to purge the chamber. The chamber will be purged by the method of dilution purging. This method is preferred because it is assumed that smoke will be formed in the production process. Dilution purging allows the flow to remain while the piece is being manufactured. According to the used graph in Figure 4.2.2 and the mentioned flow, the vessel will be purged with 2.4 vessel volumes per minute at 2 atmospheres. This results in a ratio of around 1:100 between the initial gas and the gas in the chamber after two minutes of purging. Assuming 21% oxygen in the chamber and 0% oxygen in the nitrogen mixture at the start, this means a level of 0.21% oxygen in the chamber at the end of two minutes of purging. Combining this with the size of the chamber results in around 0.02 mL of oxygen in the chamber. For the sake of simplicity it will be assumed that this can be burned out by etching a sacrificial shape on the wood object. This shape will be a circle around the edge of the substrate.

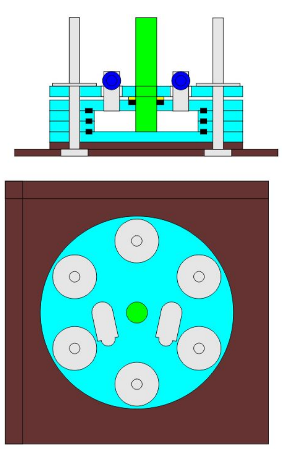

Figure 4.2.1 side and top view of the reaction chamber.

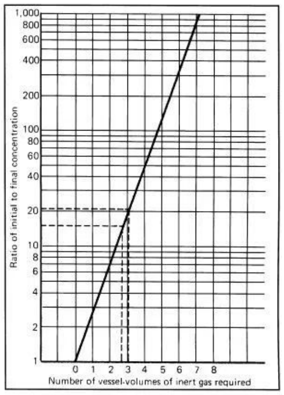

Figure 4.2.2 relation between original vessel content and number of vessel volumes pumped through [41].

The test shapes that will be made are meant to test the variability of resistance as a function of length, width and laser power of the etched path. The paths will be square to increase the distance possible on the small work surface but reduce complexity of the paths.

For testing the effect of laser power the lines will be parallel, of equal thickness but on different grayscale levels. The grayscale value is proportional to the laser power in etsching mode. The values that will be tested are all decades from 10% to 100% etching power.
The effect of length is measured by having multiple interrupted squares, where the distance between measuring points varies, but every measuring point is only connected to one complementary point to prevent measuring errors. The lines will be 0.2mm wide and have lengths of 2mm for testing short distances and from here on follow the formula distance x*4-1, where x is the base length and height. This enables to calculate the circumference of squares with a 1mm hole in them like displayed in 4.2.3. X will vary with 1mm intervals from 3mm to 7mm.

For testing the effect of width, parallel lines of different thickness but equal length will be etched and measured. The thicknesses that will be measured are between 0.2mm to 0.65mm with 0.05mm intervals. Top to bottom this will be: 0.2mm, 0.65mm, 0.3mm, 0.55 mm, 0.4mm, 0.45mm, 0.5mm, 0.35mm, 0.6mm and lastly 0.25mm. This order is chosen to keep as much distance between the individual lines by putting thick lines between thin lines.
These designs are depicted in figure 4.2.3

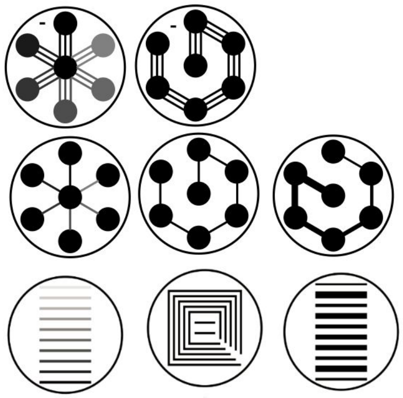

Figure 4.2.3 Three designs for testing the effects of laser power, line length and line thickness on resistance. From bottom to top, first generation, second generation and third generation patterns.

Measuring will be done by use of a multimeter on the endpoints. This is regarded as the most quick method of measuring. This however will be done twice. Once with dry electrodes and material and once with covered nodes. The nodes will be covered in conductive silver epoxy. The results of this will be graphed and then further interpreted if any resistance is found

These tests will be done on multiple types of wood to indicate the effect of tree species on conductance. Therefore all three tests will be repeated at least as many times as there are wood types available for this research. The wood types used will be: pine, birch, poplar plywood and birch plywood. The sample plates will be cut to be no taller than 12mm as taller pieces do not fit in the chamber without adding additional rings to the chamber stack.

The results will be projected on a graph to extrapolate possible contact resistance and be able to identify and isolate possible strange phenomenon. This will be done for every tested wood type. Other interesting phenomenon, like smoke development, charring and resulting lines will be written down in appendix C. The resulting table will be comprised of the following entries: test identification (letter for the session, number for identification), the used laser power, etching speed, pulse frequency in PPI, nitrogen pressure in psi (this is easier to read off the valve), wood type, vertical offset from a focused top, measured resistance, glossy (wet) look properties and charing occurrence. Additionally all notes made during the lab sessions will be in appendix B.

4.3 Test results

User questionnaires

The exact results can be found in appendix D. The questionnaire was promoted on facebook, linkedin and via personal channels like whatsapp and personal real world contact. This resulted in 31 people filling in the survey. Of these people 15 self identify as makers, 4 as scientist and 3 as engineer. One person claimed to belong to both makers and scientists. 8

people filled out the questions but claimed to belong to other groups. These people will be regarded as general public.

Most people, 21 were between the ages 20 and 25, the second largest group, 8 people were older than 30, and only two people were either between 25 and 30 or younger than 20. Further, only 9 people didn't claim to have the maximum score on the question about knowledge of electronics, where the knowledge about bio-degradation, was very normally distributed with a small skew into the positive. Skepsis was skewed largely into the negative. Another interesting observation is the overwhelming majority (87%) of respondents were in favor of a circular economy. Only 4 people didn’t in some way support a circular economy. The questions after the second page, are interesting to view per user group. Therefore, the answers will be grouped by user section and analysed in that way.

The scientist group is the first to be separately analysed. The first question that stands out is the question about fields where the technology could be used. All people answered they could see the technology being used for urban pollution monitoring. Monitoring sea currents and construction biodegradable sensors was supported by 3 out of the 4 respondents in this category. The monitoring of constructions was the only answer that did not get voted on at least once.

The another interesting set of questions is the set of reasons to choose and not choose biodegradable sensor nodes. All respondents noted cost as an important reason to buy sensor nodes, but only one noted it as a reason not to buy sensor nodes. Ecological and environmental impact were both named by three respondents as reasons to buy, but only two worries about premature degrading, making it the second most noted reason not to use the nodes. The most important reason not to use these nodes was the fact that the technology was unproven, and this was quoted by three people.

The last interesting question in this group was the question what service they would prefer. This group mostly prefered ‘ready made nodes where a sensor has yet to be attached’. This is based on the results of three out of the four scientists who responded. Another interesting observation was the fact that two people had projects to integrate the nodes into, but no idea of other projects, where this was opposite for the other two respondents.

Opposite to the scientist, all engineers proposed using the nodes for monitoring constructions. They were also unanimously in favour of monitoring illegal logging, and monitoring garbage sites with this technology. No answers have been given less than once or more than twice apart from the before mentioned ones.

The reasons for use were in this group based unanimously on ease of use and ecological impact. Two out of three also though lack of maintenance and biodegradability to be important factors. The unproven technology and premature degrading answers were both leaders in the counter arguments section with both only two votes. All other options were mentioned less. The limited lifespan and compatibility with existing sensor networks being the only two other given answers.

Interestingly enough, none of the engineers agree on what type of service they would prefer. This could very well be an effect of the small number of respondents in this category.

Makers agree that in terms of use fields, monitoring urban pollution, researching wildlife movements and constructing biodegradable computers are good fields, as is indicated by the score of 13 out of 15 votes. The monitoring of constructions has again a low score of only five votes. Reasearchin sea currents and constructing biodegradable sensors however got voted on 12 times. Monitoring of illegal logging and hunting and constructing biodegradable embedded systems got voted on 11 times. All other options got voted on either eight or nine times.

In terms of buying, most makers find the ecological impact important (13 votes), but few care about the ease of use (four votes). Cost and biodegradability are also found important with respectively ten and 12 votes. The other options were voted on 6 and 7 times. In the negative version of the same question, the limited lifespan was deemed the most important reason not to purchase with 11 votes. This is interesting as this is the only group where the non proven nature of the technology is less important, although it is a solid second reason with 10 votes. Cost in this sense only got five votes. This is interesting because it was an important reason to buy the nodes, but apparently less of a reason not to buy the nodes.lack of distributed computing was however not a reason at all with the least votes (three).

Others are the group that remains after the previous three groups have been established. This group agreed with the previous group that urban pollution monitoring is a great potential goal, however they also find that constructing biodegradable sensors and researching sea currents are promising fields. These options both got voted on seven times, this can be seen as unanimously as one person in this group refrained from voting, stating he/she could not muster the enthusiasm to fill in the entire survey. No question got less than four votes.

In terms of product purchasing reasons lack of maintenance and cost were the most important factors with seven votes each. Flexibility of usable sensors and ease of use got respectively four and five votes deeming them the least important aspects, yet still highly important at and above 50% of the votes. In the negative sense cost only got two votes where lack of distributed computing only got one vote. Limited lifespan got a total of six votes in this group, deeming it as a problem. This is remarkable as the core function of a biodegradable sensor node is degrading.

Another interesting observation is that this group, in contrast to the other user groups, greatly prefer fully installed sensor networks over the other option by five votes. The other votes were singular in other categories with one unique answer “Easy to use without difficult operation requirements. So most important for me: high customers support and no fuss.”.

Other unique answers were found in the proposed projects. These answers are no longer sorted by user group, as they indicate interesting future fields more than that they give direction. What follows is a list of the most constructive and interesting projects reported in the survey. Most answers have been rewritten to make them more readable in this list form.

- People and businesses will love the positive marketing they will get out of using this or a similar product
- Monitoring earthquake areas, medical devices and operation systems, monitoring storms/weather for early warning systems.

- Construction of a biodegradable phone and computer
- Measuring the way visitors behave on a festival
- A weather balloon
- Monitoring a building over time, so you can see the wear
- Monitoring forest fires
- Monitoring building sites
- Climate control inside a building (smart air conditioning), or to balance the strain put on 'difficult' elements (like a bridge or a load bearing wall).
- Measuring ocean temperature change
- To research/monitor anything before you actually start building to get a better insight in the ground/environment where you will be building.
- Wearable sensors
- A large scale analysis of mobile data usage in multiple environments
- Climate sensing in public spaces project
- Correlating morbidity and mortality in urban or rural areas with several measurable biomarkers in those regions.
- Biodegradable robots
- Monitoring insect populations.
- Monitoring of resource levels (soap, toilet paper etc.) in toilets
- Long term noise/sound pollution analysis
- Monitoring sea life
- Studying the movement of waves (Anouk de Bakker works on this)
- Tracking underground oil streams and Climate around rural areas
- Agriculture and for ecologists, and I definitely see possibilities there

Resistive tests

The first generation paths were etched without noting laser cutter settings. This was treated as a first ‘wet try’ to see if problems would occur with the setup and test design. All paths were however cut, and the middle path in image 4.2.3 did give positive results. The probes however destroyed the porous graphite structure and the results couldn’t be repeated. The destruction was confirmed under a microscope as can be seen in appendix B. Similar resistive effects have also been observed in untreated wood.

The second test session used second and third generation paths. These and following tests were noted down. The third generation paths were based on the observation that laterly close paths gave better charring and possible grafite. Another improvement was the design of pads to prevent the probes from destroying the porous graphite. Lastly the case was modified to include a clamp system in order to increase the possible gas pressure without sacrificing the stability of the workpiece due to the gas stream.

The third test session went smooth until the outflow adapter was completely blocked and could not be cleaned with the available equipment. Therefore this test was cut short. However, the gas flow was not constant as the outlet of the chamber got clogged during cutting. This clogging was cleaned after every test, but as it turned out, the cleaning tool did not reach into the elbow adapter far enough to prevent it from closing completely. After cleaning with a needle the residue seemed to be a hardened oily substance, this was likely vaporized tar. This incident however illustrates that this problem likely occurred in all test, indicating that regardless of stability in gas pressure, the flow was not constant. This could be an explanation for the different results with same settings.

No conductance has been achieved even when conductive silver epoxy was applied to the measurement nodes. The exact notations and pictures of all results can be found in appendix B.

5 Evaluation

5.1 evaluation of questionnaire

The survey was filled in by 32 people who were among four user groups. These groups were not represented evenly among the surveyed people. Most were makers, and only a few were scientists(self reported). This led to little gain in knowledge about the scarcely represented groups. Another issue was the fact that many people were personally asked to fill in the survey. This lead to many people personally knowing the researcher and thus not being a random sample. This could very well lead to an ideological skew. Lastly and mainly, the questions were made purely for this questionnaire and can be interpreted in many ways. This leads to varying answers due to misunderstanding instead of due to intrinsic values or needs.

Even though these problems all occured, conclusions can be made. The first conclusion being, no person reacted negatively to the research topic, and many indicate their positive attitude towards biodegradability. Many people also reacted positively to the personal involvement questions. Actual differences have also been observed in the type of projects proposed by the different groups. This indicates that these groups actually have different needs and use cases, and the right assumption has been made in splitting these.

5.2 evaluation of research and tests

After more research it is highly likely that the lack of resistance, was due to the different gas type used. It was found that the original method of setting up the chamber by the Rice university team, closely resembled CVD (chemical vapor deposition) methods. Specifically of creating graphene structures on copper substrate. This is in contrast to the claim in the Rice university paper that claimed the gas mixture was intended to prevent oxygen from contaminating the chamber [26]. It is speculated that the method using a laser cutter pyrolysis the wood creating among other gases, methane. Methane is usually the carbon source in CVD of graphene. The carbon ‘crystals’ in this case grow on wood instead of copper. This would explain the shape of graphene fragments in the paper as the carbon can’t form flat crystals on the microscopically uneven wood terrain, and it would explain the presence of hydrogen and its use in the process. Before this can be claimed more research has to be done however. Alternatively, the pyrolysis of wood can produce graphene-oxide, which in turn can be reduced by a laser of the specific wavelength used. This however does not explain the use of hydrogen in the original test, nor does it explain why no resistances were measured. The only conclusion that can be made is that the tests done have not produced any conductive materials.

An additional problem could be that the reaction chamber was made of acrylic and was not inert as is commonly used for CVD processes. Usually quartz glass is used for these processes to avoid contamination and unwanted reactions.

5.3 recommendations

In terms of user tests, it is recommended to find more scientists and engineers to fill in a survey based on the one used, but made more neutral as to steer people less into certain answers.

In the line of this research it seems that the best market applicable conductor material would be biodegradable carbon based conductive ink. This ink can be used by inkjet printers, or silkscreen printers, for respectively small and large product amounts, to be reliably produced. This seems to be the better solution, as the material requirements are less, simpler and the application is a less of a critical process. Additionally, different volume percentages of carbon can be used to achieve different resistive properties. Further research into this is required. However, this would likely be mainly paper based research as the carbon ink materials are already more widely used.

If the route of laser etching is followed further however, the recommendations are to find out the exact chemical process, and testing the same aspects of conductivity as before, with the addition of a glass chamber and hydrogen argon gas mixture. It is also recommended to investigate the possibility of etching lignin directly without the interference of wood. This is possible as lignin is a waste product of the paper industry. This also potentially enables the circuits to be flexible, as the substrate on which the lignin is deposited can be flexible.

5.4 Future work roadmap

At the beginning of this research, little was known about the hurdles and steps that had to be taken to make biodegradable sensor nodes a reality. Now, with the gained knowledge, it can be determined what those steps are and in what order the hurdles have to be overcome. This plan consists of the following steps.

- Develop practical, scalable, conductors that can be mutated to act as resistors.
- Apply the previous knowledge to planar inductors and capacitors
- Develop practical, scalable, biodegradable OFETs
- Combine the previous methods into one process and show this works
- Start improving on the previous system in terms of scale, power use, ecological impact and scalability

This lists the main milestones while disregarding smaller achievements and steps. It is however clear now that any work on biodegradable electronics will have to pass through these stages.

Specific to the performed study, more interesting findings and additional value are expected to be in finding alternative power harvesting methods to prolong the battery life of nodes, via for example energy harvesting from plants [42]. Further relevant research, on the part of the nodes is expected to be in combining the sensor nodes with simple organisms as sensors. Think of a conductive organism that thrives in regular conditions but dies when radioactive material is present in high doses as a biodegradable radiation sensor.

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Appendix A

Biodegradable sensor nodes

This questionnaire is aimed at finding out if there is a place for biodegradable sensor nodes in today's market. The questions asked here are aimed at finding out whether earlier assumptions were correct and whether certain aspects were overlooked or over emphasized.

This questionnaire is completely anonymous. You can stop at any point although it will be greatly appreciated if you fill in all questions. Even if you feel you do not belong to the desired group, your awnsers are still very valuable.

Have fun and thank you for your time.

* Required

1. How would you describe yourself? *

Mark only one oval.

Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)

Scientist (involved or interested in field research)

Engineer or architect (involved or interested in building or landscape planning, construction or maintenance)

Other:

2. How old are you? *

Mark only one oval.

under 20

between 20 and 25

between 26 and 30

over 30

3. What is the field of your occupation? *

A little bit more about you The next questions are aimed at getting to know you a little bit better. If you are not familiar with the concepts, don't worry, it will all be explained.

4. I am familiar with electronics on at least a highschool level

Mark only one oval.

1 2 3 4 5

Fully disagree Fully agree

5. I am familiar with the proces of bio-degradation.

Mark only one oval.

1 2 3 4 5

Fully disagree Fully agree

6. I am usually very skeptical of new things

Mark only one oval.

1 2 3 4 5

Fully disagree Fully agree

7. The current state of electronics manufacturing and disposal has inherent flaws

Mark only one oval.

1 2 3 4 5

Fully disagree Fully agree

8. What is the best future for the global economy

Mark only one oval.

A less controlled economy where companies decide what's best for the economy.

A more controlled economy where government decides what is good for the economy.

Forming a renewable circular economy that leads to a stable resource base.

Mining and colonizing planets and asteroids to increase available resources for a growing economy.

Mining and colonizing oceans and seas to increase available resources for a growing economy.

Other:

Biodegradable sensor nodes and you Instead of a wall of text, you can watch the video below. This will explain what a biodegradable sensor node is, what it does and why it does this.

http://youtube.com/watch?v=cPk-kavZY_4

9. Would you consider using a sensor node as described above in a project you are or will be working on? (Please describe what project.)

10. Would you see this technology being used in any other project (not done by you)? And, could you give an example?

11. Would you see this technology being used in any of the following fields, select as many as

you want. Check all that apply.

monitoring of pollution in urban environments

monitoring of constructions

monitoring of illegal hunting in nature reserves

monitoring of illegal logging in nature reserves

monitoring of flood protection devices

researching sea currents

researching wildlife movements

researching high altitude conditions

researching garbage dump sites

researching flood plains

constructing biodegradable radios

constructing biodegradable embedded systems

constructing biodegradable robots

constructing biodegradable 'computers'

constructing biodegradable sensors

Other:

Critical questions As with any technology, it can only be adopted and used when the barriers of use are low and the benefits of use are great. This section aims to understand those factors better.

12. Imagine you are a contractor interested in using the sensor node technology in a project.

What project would that be?

13. What would be the most important aspects for you to choose biodegradable sensor nodes over other technologies? (Multiple awnsers can be given.) Check all that apply.

Ease of use

Lack of maintanance requirement

Cost (estimated around 10 cents per node)

Biodegradability

Ecological impact

Flexibility in usable sensors

Other:

14. If you chose 'other' please specify as many reasons as you can think of.

15. What would be the most important reasons not to use Biodegradable sensor nodes?

Check all that apply.

Not being able to use digital sensors

Limited lifespan

Limited in-operation adaptation options

Unproven technology

Possibility of premature degrading

Cost

Lack of distributed computing capabilities (nodes can only send data)

Measurement quality

Compatibility with existing sensor networks

Lack of official licences

Other:

16. If you chose 'other' please specify as many reasons as you can think of.

17. If in the end you chose to go for the biodegradable option, what type of service would you (the contractor) prefer? Mark only one oval.

Fully installed sensor networked as specified by you

Ready made nodes where a sensor is attached and interfaced

Ready made nodes, where only a sensor has to be attached

Plans to make nodes and the devices to do so

Plans to make nodes

Other:

18. If you chose 'other' please specify.

Lastly

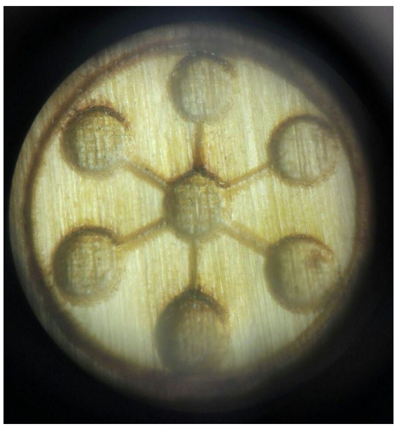
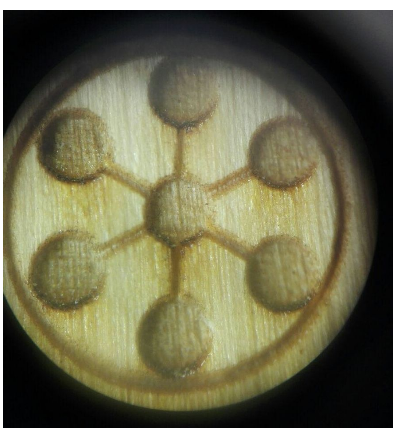
19. If you have any other comment or ideas for this research please put them down here

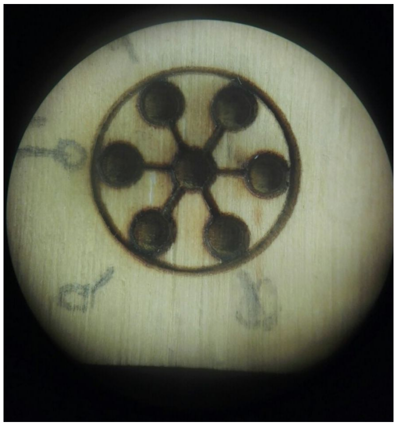
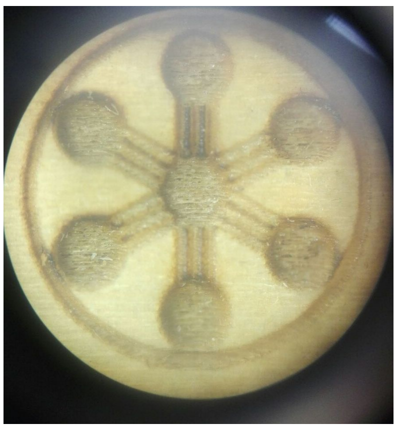
20. If you would like to ask a question please put it down here, with an e-mail adress to respond to.

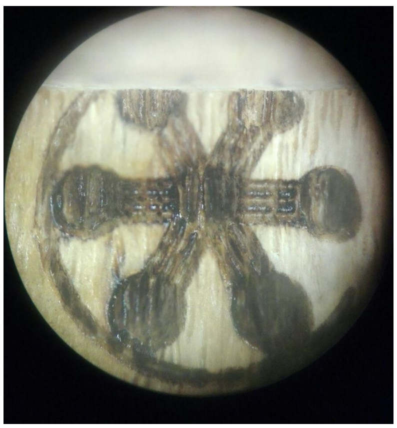
Appendix B

In all tests, unless mentioned otherwise the following settings have been used. Laserspeed 12, pulse frequency 1000 and birch plywood.

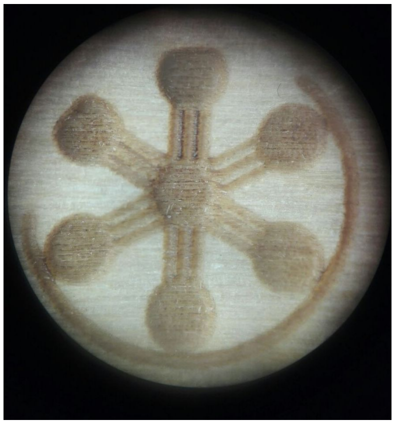
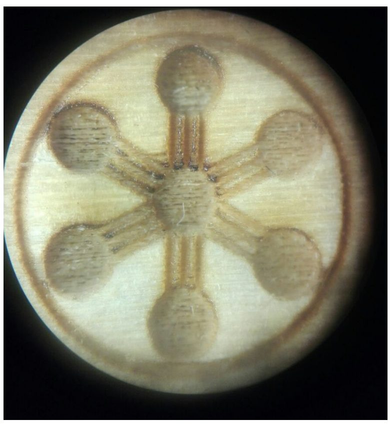
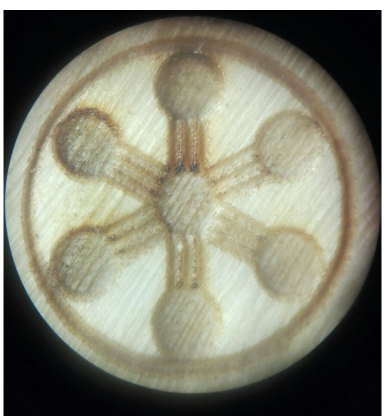
Session A

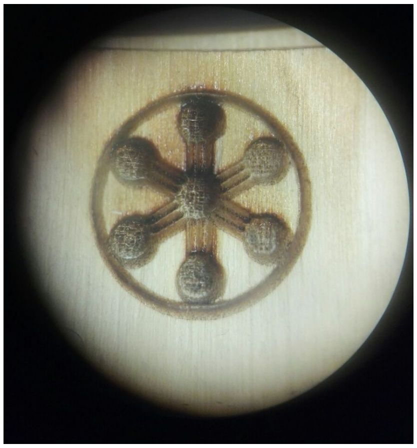
nr.	Image	Notes
1		Observations: looks wet, shiny brown, no visible graite, visible craters. Settings: laser power%: 70, nitrogen pressure: 1.4psi
2		Observations: uniformly wet coated, small amounts of charring, less visible craters Settings: laser power%: 75, nitrogen pressure: 4psi

3		Observations: visible charring, white deposits, no wet look, visible laser dot grid, white smoke on opening of the case Settings: laser power%: 75, nitrogen pressure: 4psi, double sequentially engraved
4		Observations: lots of white smoke while cutting, smoke so thick the test object is not seen in the chamber, object sticky to touch, outlet was clogged with charred wood particles Settings: laser power%: 95, nitrogen pressure: 4psi
5		Observations: strong wood smell, wet look, small patches of charring, edge charring on 70% line is most Settings: laser power%: 95, nitrogen pressure: test done outside chamber in air, wood type: pine

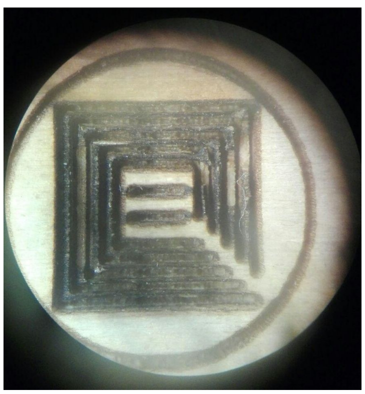
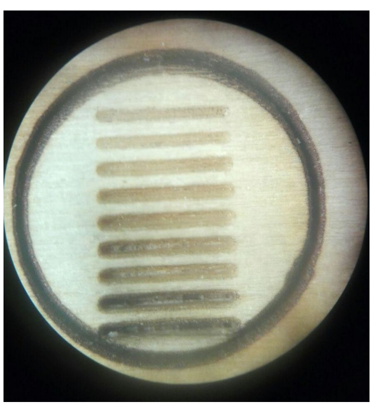
6a		Observations: very prominent charring, cut out of focus Settings: laser power%: 85, nitrogen pressure: 1.4psi, wood type: unknown veneer
6b		Observations: wet look, very good charing along the edges, white spots Settings: laser power%: 85, nitrogen pressure: 1.4psi, woodtype: birch wood
7		Observations: much charing, no individual lines visible, wet look, first cutting test was abandoned half way, then realigned and re-engaged. Settings: laser power%: 70, nitrogen pressure: 1.4psi, z-offset 6mm

Session B

1		Observations: no charing, no wet look, smelled like unburned wood, misaligned Settings: laser power%: 85, nitrogen pressure: 6 psi, z-offset from focus: 10mm
2		Observations: little wet look, slight charing around middle circle Settings: laser power%: 85, nitrogen pressure: 6 psi, z-offset from focus: 5mm
3		Observations: more wet look, slight increase in charing Settings: laser power%: 95, nitrogen pressure: 6 psi

5		Observations: adapter in test 4 clogged and could not be fixed, more charing, white spots, visible laser grid Settings: laser power%: 95, nitrogen pressure: 6 psi, z-offset from focus: 4mm

Session test

1		Observations: slight resistance, very brittle, very prominent charring, no wet look Settings: laser power%: 100, nitrogen pressure: 1.4 psi
2		Observations: propper linear increase in charing over linear increase in laser power Settings: laser power%: 100, nitrogen pressure: 1.4 psi, wood used: poplar plywood

Appendix C

test letter	test nr	laser power in %	laser speed	pulse frequency	nitrogen pressure	wood type	z offset (compared to in focus top surface)	Ω	wet look	charring
A	1	70	12	1000	1.4	birch ply	0	∞	yes	none visible
A	2	75	12	1000	4	birch ply	0	∞	yes	small amounts
A	3	75	12	1000	4	birch ply	0	∞	no	visible charring and white deposits
A	4	95	12	1000	4	birch ply	0	∞	no	good charring
A	5	95	12	1000	4	grenen	0	∞	yes	the 70% line is most charred
A	6a	85	12	1000	4	birch	0	∞	yes	very much charring and white spots
A	6b	85	12	1000	4	veneer (unknown type)	6	∞	no	very prominent
A	7	85	12	1000	4	birch ply	0	∞	yes	much charing, no visible lines
B	1	85	20	1000	6	birch ply	10	∞	no	none
B	2	85	12	1000	6	birch ply	5	∞	little	slight on vertical surfaces
B	3	95	12	1000	6	birch ply	0	∞	yes	slight charring
B	4	-	-	1000	6	birch ply	-	∞	-	-
B	5	95	12	1000	6	birch ply	4	∞	no	In air
B	z1	85	12	1000		birch ply	0	∞	no	In air

Appendix D

The document of responses was to big to fit normally on a single page. Therefore the data has been cut up. A single respondent has a single identifier that remains constant over all pages.

identifier	How would you describe yourself?	How old are you?	What is the field of your occupation?	I am familiar with electronics on at least a highschool level	I am familiar with the proces of bio-degradation.	I am usually very skeptical of new things	The current state of electronics manufacturing and disposal has inherent flaws	What is the best future for the global economy
1	Engineer or architect (involved or interested in building or landscape planning, construction or maintenance)	between 20 and 25	Architect	3	5	1	4	Forming a renewable circular economy that leads to a stable resource base.
2	Engineer or architect (involved or interested in building or landscape planning, construction or maintenance)	over 30	Oil & Gas	5	4	1	5	Forming a renewable circular economy that leads to a stable resource base.

3	Engineer or architect (involved or interested in building or landscape planning, construction or maintenance)	over 30	Building pensionado	1	3	4	5	Forming a renewable circular economy that leads to a stable resource base.
4	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	betwe en 20 and 25	Student	5	5	3	5	Mining and colonizing planets and asteroids to increase available resources for a growing economy.
5	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	under 20	Creative Technology	5	2	2	4	Forming a renewable circular economy that leads to a stable resource base.
6	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	betwe en 20 and 25	Industrial Design	5	4	2	5	Forming a renewable circular economy that leads to a stable resource base.

7	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Technical product designer	5	3	1	4	Forming a renewable circular economy that leads to a stable resource base.
8	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	inventor/entrepreneur	5	5	3	5	Forming a renewable circular economy that leads to a stable resource base.
9	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Electrical Engineering	5	2	3	4	Forming a renewable circular economy that leads to a stable resource base.
10	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	student	5	1	3	3	Forming a renewable circular economy that leads to a stable resource base.

11	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	IT	5	3	3	4	Forming a renewable circular economy that leads to a stable resource base.
12	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	CreaTe	5	3	2	3	Forming a renewable circular economy that leads to a stable resource base.
13	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Engineering Student	5	3	2	5	Forming a renewable circular economy that leads to a stable resource base.
14	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Post-(bachelor-)graduate	5	5	2	4	Forming a renewable circular economy that leads to a stable resource base.

15	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Student	5	4	1	5	Forming a renewable circular economy that leads to a stable resource base.
16	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Student Creative Technology	5	4	5	5	Forming a renewable circular economy that leads to a stable resource base.
17	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Student	5	4	3	4	Forming a renewable circular economy that leads to a stable resource base.
18	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	Programming	5	3	3	5	Both forming a renewable circular economy that leads to a stable resource base and mining and colonizing planets and asteroids to increase available resources

								for a growing economy
19	Maker (interested in or actively involved in STEM (Science, Technology, Engineering, Mathematics) projects)	between 20 and 25	MSc Student in Embedded Systems	5	3	4	5	combination of option 3, 4 and 5
20	Scientist (involved or interested in field research)	between 20 and 25	creative technology	5	4	2	4	Forming a renewable circular economy that leads to a stable resource base.
21	Scientist (involved or interested in field research)	between 20 and 25	Epidemiologic research	5	5	4	4	Forming a renewable circular economy that leads to a stable resource base.
22	Scientist (involved or interested in field research)	over 30	3D printing	5	5	2	4	Forming a renewable circular economy that leads to a stable resource base.
23	Scientist (involved or interested in field research)	over 30	Research & Education in Mechatronics	4	3	2	5	Forming a renewable circular economy that leads to a stable resource base.

24	simply interested	over 30	communication	4	4	3	4	Forming a renewable circular economy that leads to a stable resource base.
25	Student	between 20 and 25	Product development	5	3	4	3	A more controlled economy where government decides what is good for the economy.
26	Student	between 20 and 25	Combination of engineering, design and programming	5	3	2	3	Forming a renewable circular economy that leads to a stable resource base.
27	Just interested in scientific innovation's	over 30	Artist and ' ambtenaar'	4	2	1	5	Forming a renewable circular economy that leads to a stable resource base.
28	Law student	between 20 and 25	Law/administration	3	2	4	5	Forming a renewable circular economy that leads to a stable resource base.

29	Nurse	between 20 and 25	healthcare	3	1	3	4	Forming a renewable circular economy that leads to a stable resource base.
30	Psychologische kant innovatie	over 30	Education	3	2	1	4	Forming a renewable circular economy that leads to a stable resource base.
31	All of the above minus Engineer?	between 26 and 30	Human Media Interaction	5	2	1	4	Forming a renewable circular economy that leads to a stable resource base.
32	artist, teacher, creator, thinker.. and much more, but non of the above	over 30	teaching	2	1	3	4	Forming a renewable circular economy that leads to a stable resource base.

identifier	Would you consider using a sensor node as described above in a project you are or will be working on? (Please describe what project.)	Would you see this technology being used in any other project (not done by you)? And, could you give an example?	Would you see this technology being used in any of the following fields, select as many as you want.	Imagine you are a contractor interested in using the sensor node technology in a project. What project would that be?

1	Construction equipments and building materials	Building construction	monitoring of constructions, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching garbage dump sites, constructing biodegradable embedded systems, constructing biodegradable 'computers'	Building construction
2	Considering yes, but not involved in any relevant project at the moment	For remote areas (jungles, rough terrain) where nodes are dropped from helicopter over specific area	monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, researching wildlife movements, researching high altitude conditions, researching garbage dump sites	One in which placement/removal of biodegradable nodes is over the lifetime of the specific project more attractive (with or without subsidies...)

3	i’m not working on any projects, but i’m certainly in favour of. Biodegradability	See previous answer	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors, Not just the above, but a good clean-up too!	All possible projects

4	Depends on the functionality, there are projects I don't want to be biodegradable, e.g. a temperature sensor network that should withstand the weather outside for mutliple years	yes, for projects that send out sensors in an environment with a lot of wildlife. Or a project with a limited time scope	monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	a project with sustainability in mind

5	Not as of now, but I probably will in the future	Yes, for instance by measuring the current state of the rain forest and seeing where people can act in such a way that nature profits from it.	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	Measuring the way visitors behave on a festival

6	As I often work with re-usable prototype building things (Arduino etc) I don't know if I could use this right now. If I could, and it wouldn't be expensive (starving student here ;P) I'd definitely use it :)	Yes. Example: monitoring insect populations. It's hard to monitor insect populations without harming them (having to catch them etc) so this technology might be able to help with that.	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, researching sea currents, researching wildlife movements, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors, all sorts of things that have a short use life (phones, earbuds, etc). Also anything that needs to monitor something in nature for a short period of time (otherwise it would degrade to fast?)	Anything with a short use life or that would need to be placed in nature.
7	Wearable sensors	Monitoring of resource levels (soap, toilet paper etc.) in toilets	monitoring of pollution in urban environments, monitoring of constructions, constructing biodegradable embedded systems, constructing biodegradable 'computers'	

8	sure, but depends on the availability.	sure, nature/general monitoring	monitoring of pollution in urban environments, researching sea currents, researching wildlife movements, researching flood plains, constructing biodegradable 'computers', constructing biodegradable sensors	any applications where the sensor could come into contact with wild life
9	That depends on the functionality and durability of the sensors, I would not want to replace them every half year or so.	Wildfire detection (uses a sensor network like the network shown in the video)	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, researching sea currents, researching wildlife movements, researching high altitude conditions, constructing biodegradable sensors	Any project where you have sensors that are difficult to retrieve after use
10	-	Yes, for example tempreture measuring	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable robots, constructing biodegradable 'computers'	monitoring something

11	I would definitely consider using bio degradable sensor nodes in a project, especially if the sensor nodes aren't expected to have a long life cycle. I'm not currently working or planning to work on a project where this technology could be used.	Yes, I think this could be revolutionary for technology like weather balloons, where the electronics are often single-use, and often can't be retrieved after usage. In other environments where retrieving the sensors is difficult, sensor nodes that naturally degrade after the project has been completed would also be very useful. One thing to consider, however, is that there might be a risk of the nodes degrading before they have reached the end of their planned use time, and therefore increasing the production of new nodes to replace the degraded nodes.	monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	A weather balloon
12	Sounds cool, not really working in the practical field though, but if, this is really useful	any remote sensing project.	monitoring of pollution in urban environments, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching garbage dump sites, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	Something with animal tracking sounds logical to do with it

13	Sensor nodes aren't too interesting for projects I am working on. But I think biodegradable electronics are a very important innovation.	I think it will be used for sure. Perhaps for monitoring remote systems or something. But I can't really give a concrete example.	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors, Monitoring the functioning of remote mechanical systems, such as wind turbines	Making a more accurate weather measurement system by placing nodes all over the place.
14	Yes, in a large scale analysis of mobile data usage in multiple environments	Yes, long term noise/sound polution analysis	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions	A large scale research for another project's focus areas

15	Yes, it can be used for many projects	Yes, monitoring sea life	monitoring of pollution in urban environments, monitoring of flood protection devices, researching wildlife movements, researching garbage dump sites, researching flood plains, constructing biodegradable embedded systems, constructing biodegradable 'computers', constructing biodegradable sensors	monitor a building over time, so you can see the wear
16	Yes, although I don't quite focus on technology in nature I think I would take my footprint of trash into account.	If a company or group focuses on green technology then yes. Bigger companies are probably less likely to make the switch.	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, researching wildlife movements, constructing biodegradable embedded systems, constructing biodegradable 'computers', constructing biodegradable sensors	If biodegradability would be a factor, I would think of long-term projects in nature like wildife or pollution tracking.

17	Yes but I am currently not working on a project	Any type of real world data collection project seems fit	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable embedded systems, Monitoring any type of traffic	A data collection project
18	Yes possibly, it depends on how long the sensor nodes would actually last. Dont have a specific project in mind.	Meteorological sensors in remote areas,	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable 'computers', constructing biodegradable sensors	Monitoring forest fires

19	Yes, if it is on the market or easily available and meets performance standards. The application would be, like you said, in WSN's. Or, hopefully as a substitute for non-biodegradable consumer electronics such as cellphones or other devices.	Yes; repeating answer to the previous question: the application would be, like you said, in WSN's. Or, hopefully as a substitute for non-biodegradable consumer electronics such as cellphones or other devices.	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	Measurement of the water conditions of the Great Barrier Reef.
20	yes in a climate sensing in public spaces project	no idea	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching flood plains, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	monitoring building sights

21	Correlating morbidity and mortality in urban or rural areas with several measurable biomarkers in those regions.		monitoring of pollution in urban environments, Monitoring radon levels in urban areas	
22	No current project	Tracking underground oil streams and Climate around rural areas (old projects)	monitoring of pollution in urban environments, researching sea currents, constructing biodegradable radios, constructing biodegradable sensors	Something with water flow
23	We might think of biodegradable robots	I did projects for agriculture and for ecologists, and I definitely see possibilities there	monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	Probably something with monitoring for agriculture or wildlife

24	I don't do projects in which I could use it, but if I would I would consider it :-)	yes, maybe medical use (like more accurate, continuous blood pressure-measurements) or animal care (like 'clean' temperature measurements in a stable). Maybe you could even use it to detect wave patterns early, to prevent casualties in case of a tsunami? Basically everything in which continuous measurements are usefull, but it's hard to afterwards collect your sensor/protect the surroundings from toxic waiste. I wrote this before I read the next question, so I realise now what I described is allready listed. :-)	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors, possibly some medical uses, in which the sensor is slowely dissolved inside the body and does not need to be retrieved	Maybe I could use it in climate control inside a building (smart airconditioning), or to balance the strain put on 'difficult' elements (like a bridge or a supporting wall).
25	Yes, a fall detection project for elderly	Yes, Australia's sea temperature measurement sensor network	monitoring of pollution in urban environments, monitoring of poaching in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching high altitude conditions, researching flood plains, constructing biodegradable sensors	Measuring ocean temperature change

26	I would use it in a project if some kind of data needs to be gathered, especially since it is able to communicate with other nodes and can therefore more information (if I interpreted the video correctly).	I think this technology has potential, because information gathering and environmental friendly products/technologies are very important in those times.	monitoring of pollution in urban environments, monitoring of flood protection devices, researching sea currents, researching high altitude conditions, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	To research/monitor anything before you actually start building to get a better insight in the ground/environment where you will be building.

27	Definitely a Yes, unfortunately i'am not working on such project's but i would support the people who do	There are likely to be similar project's ongoing in other countrie's, perhap's just as unexpected as Dylan's project and idea's. Because the planet (life as we no it) is at stake and the clock is ticking, it can always come in handy to network and wonder about new exciting possibilitie's which are unlimited in my opinion. Using Dylan's technology with further development and research could also stretch out to space travel in the future because this would become also cheaper on account of using unexpected technologie's and material's in the future. Further use for the list below: Also monitoring earthquake area's, medical devices and operation system's, monitoring storms/wheather for early warning system's.	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors, And space technology in order to keep the space cleaner with less garbidge flying around or falling down into our athmosfere	Construction of a biodegradable phone and computer
28			monitoring of pollution in urban environments, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, researching sea currents, researching garbage dump sites	

29	I don't realy think my projects wil include needing a sensor node. But wen they do I think biodegradeble is better than things that pollute.	Yes, by a scientist who studies the movement of waves in France. (Anouk de Bakker)	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	A pressure sensitive node for under beds of patiënts so the weight can be monitord propperly. Or pressure modes under the bed or chair who feel in when patiënts have seizures.
30	Yes. No idea in what.		monitoring of illegal hunting in nature reserves, researching flood plains, constructing biodegradable radios, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	Hospital, elderly home

31	No because the main field I am working in does not work with sensors. If I need to work with sensors than I would not care if it does or does not work with a biodegradable shell	If it is sustainable and realistic to use in a real world scenario I think people and businesses will love the positive marketing they will get out of using this or a similair product	monitoring of pollution in urban environments, monitoring of constructions, monitoring of illegal hunting in nature reserves, monitoring of illegal logging in nature reserves, monitoring of flood protection devices, researching sea currents, researching wildlife movements, researching high altitude conditions, researching garbage dump sites, researching flood plains, constructing biodegradable radios, constructing biodegradable embedded systems, constructing biodegradable robots, constructing biodegradable 'computers', constructing biodegradable sensors	Nothing in particular
32				

identifier	What would be the most important aspects for you to choose biodegradable sensor nodes over other technologies? (Multiple awnsers can be given.)	If you chose 'other' please specify as many reasons as you can think of.	What would be the most important reasons not to use Biodegradable sensor nodes?	If you chose 'other' please specify as many reasons as you can think of.	If in the end you chose to go for the biodegradable option, what type of service would you (the contractor) prefer?	If you chose 'other' please specify.	If you have any other comment or ideas for this research please put them down here	If you would like to ask a question please put it down here, with an e-mail adress to

								respond to.
1	Ease of use, Lack of maintanance requirement, Ecological impact, Flexibility in usable sensors		Compatibility with existing sensor networks		Ready made nodes where a sensor is attached and interfaced			
2	Ease of use, Lack of maintanance requirement, Biodegradability, Ecological impact		Unproven technology, Possibility of premature degrading		Fully installed sensor networked as specified by you			
3	Ease of use, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Limited lifespan, Unproven technology, Possibility of premature degrading		Ready made nodes, where only a sensor has to be attached		The problem lies not only in what Will be Made in the future but in the mess we've already Made!	
4	Cost (estimated around 10 cents per node), Ecological impact, Flexibility in usable sensors		Limited lifespan, Possibility of premature degrading		Ready made nodes, where only a sensor has to be attached			

5	Cost (estimated around 10 cents per node), Biodegradability, Ecological impact, Flexibility in usable sensors		Not being able to use digital sensors, Limited lifespan, Unproven technology, Measurement quality		Ready made nodes, where only a sensor has to be attached			
6	Ease of use, Lack of maintanance requirement, Biodegradability, Ecological impact, How long it would stay 'functional' in different conditions.	If it would be used in a short use life technology: we wouldn't want it to stop working before people would buy something to replace it. It should stay at top working capabilities through it's entire use. If it would be placed in nature: it	Limited lifespan, Unproven technology, Possibility of premature degrading, Measurement quality, Compatibility with existing sensor networks		probably depends on how much money each version would cost, how much time they would take to implement, and what type of project it would be used for	probably depends on how much money each version would cost, how much time they would take to implement, and what type of project it would be used for	I mostly just want to wish you luck with finishing your project :) I really like your subject and that you are doing something with biodegradability.	

		needs to work long enough in the conditions it's placed for it to collect all the needed data (water? forrest? desert?)						
7	Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Limited lifespan, Unproven technology		Plans to make nodes and the devices to do so			
8	Biodegradability, Ecological impact		Unproven technology, Possibility of premature degrading		Ready made nodes, where only a sensor has to be attached		maybe use the sensor inside of organisms	
9	Lack of maintanance requirement, Ecological impact, Flexibility in usable sensors		Limited lifespan, Cost, Measurement quality		Ready made nodes where a sensor is attached and interfaced			

10	Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Not being able to use digital sensors, Limited in-operation adaptation options, Compatibility with existing sensor networks		Ready made nodes, where only a sensor has to be attached		Maybe also give the person filling in the form a choice to read text in stead of whatching the video. This is expecially handy for people who have no ability to play music in their current situation :)	
11	Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Limited lifespan, Unproven technology, Possibility of premature degrading, Measurement quality		Ready made nodes, where only a sensor has to be attached		I think this is a really cool research project, that could have quite a noticeable effect on our environment. Especially the possibility of replacing disposable sensor nodes with a limited lifespan, that currently just end up being abandoned, is very promising.	

12	Ease of use, Cost (estimated around 10 cents per node), Biodegradability, Flexibility in usable sensors		Not being able to use digital sensors, Limited lifespan, Unproven technology, Lack of distributed computing capabilities (nodes can only send data), ethical sides, but that's sensing in general		Ready made nodes, where only a sensor has to be attached		I found some question a bit out of the blue.	
13	Ease of use, Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradability, Flexibility in usable sensors		Limited lifespan, Unproven technology, Cost		Ready made nodes where a sensor is attached and interfaced			
14	Lack of maintanance requirement, Cost (estimated around 10 cents per node), Ecological impact, Ecologically		Unproven technology, Cost, Measurement quality, Compatibility with existing sensor networks		Ready made nodes, where only a sensor has to be attached			

	interested subsidies							
15	Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Not being able to use digital sensors, Limited lifespan, Possibility of premature degrading		Ready made nodes where a sensor is attached and interfaced			
16	Lack of maintanance requirement, Biodegradability, Ecological impact		Limited lifespan, Possibility of premature degrading, Lack of distributed computing capabilities (nodes can only send data)		Fully installed sensor networked as specified by you		You could look into territories that don't currently use any of this kind of technology to offer a nature-friendly way of introducing this technology. This could be for instance for zoos or natural parks.	
17	Ecological impact, Flexibility in usable sensors		Limited lifespan, Limited in-operation adaptation options, Possibility of premature degrading, Compatibili		Ready made nodes, where only a sensor has to be attached		I really like the concept, hope it works as well as you want them to work! Good job!	

			ty with existing sensor networks					
18	Ease of use, Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact, Flexibility in usable sensors		Not being able to use digital sensors, Limited lifespan, Limited in-operation adaptation options, Unproven technology, Possibility of premature degrading, Cost, Lack of distributed computing capabilities (nodes can only send data), Measurement quality, Compatibility with existing sensor networks, Lack of official licences		Plans to make nodes and the devices to do so		You talk about tech dumps in other countries and how this could solve that, but these are two different technologies. Sensor nodes make up a very small portion of the dumps. Technologies like cell-phones, home appliances, other home technology make up a large part, which are completely different to sensor nodes and could very hardly be made out of wood with extra carbon on top.	

19	Biodegradability, Ecological impact		Not being able to use digital sensors, Unproven technology, Possibility of premature degrading, Cost, Measurement quality, Lack of official licences, nodes need to be tamper-proof and secure if the data is sensitive		Ready made nodes where a sensor is attached and interfaced + lifetime service and documentation on networking, communication and safety (not just environmental safety, but also cyber security)	eady made nodes where a sensor is attached and interfaced + lifetime service and documentation on networking, communication and safety (not just environmental safety, but also cyber security)	Very interesting. I am not only curious about how the application in sensor nodes, but also in other kinds of electronics. It would greatly reduce the environmental damage. However, I would like to see if it is possible to have conditional degradation: not only dependent on time, but also other factors.	
20	Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Limited lifespan, Unproven technology, Lack of distributed computing capabilities (nodes can only send data)		Ready made nodes, where only a sensor has to be attached			

21	Ease of use, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Unproven technology, Possibility of premature degrading		Ready made nodes, where only a sensor has to be attached			
22	Cost (estimated around 10 cents per node), Biodegradability		Unproven technology, Cost		Plans to make nodes and the devices to do so			
23	Ease of use, Cost (estimated around 10 cents per node), Ecological impact, Flexibility in usable sensors, Available documentation and examples, large user base, support, etc.		Not being able to use digital sensors, Possibility of premature degrading, Compatibility with existing sensor networks		Ready made nodes, where only a sensor has to be attached		I still don't understand if the "sensor" works with electronics or on another base. If it is based on electronics, how is it powered?	

24	Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Limited lifespan, Possibility of premature degrading, replacing a degraded sensor with a new one if needed might be difficult in - let's say - the middle of a concrete floor/wall. Maybe this also requires less standard types of construction.		Fully installed sensor networked as specified by you			
25	Lack of maintanance requirement, Cost (estimated around 10 cents per node), Ecological impact		Limited lifespan, Unproven technology		Ready made nodes, where only a sensor has to be attached		x	x
26	Ease of use, Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradabili	I think you summed the most important ones already.	Unproven technology , Measurement quality, Compatibility with existing sensor networks		Fully installed sensor networked as specified by you		UPDATE UPDATE!! :)	

	ty, Ecological impact, Flexibility in usable sensors							
27	Ease of use, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact		Not being able to use digital sensors, Compatibility with existing sensor networks		Easy to use without difficult operation reqirements. So most important for me: high customers support and no fuss.		No comment or idea's at this point.	
28	Lack of maintanance requirement, Biodegradability		Limited lifespan, Possibility of premature degrading		Fully installed sensor networked as specified by you			
29	Ease of use, Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact, Flexibility in usable sensors		Not being able to use digital sensors, Limited lifespan, Unproven technology, Cost, Lack of official licences		Fully installed sensor networked as specified by you			

30	Ease of use, Lack of maintanance requirement, Cost (estimated around 10 cents per node), Biodegradability, Ecological impact, Flexibility in usable sensors		Limited lifespan, Limited in-operation adaptation options, Unproven technology, Possibility of premature degrading, Compatibility with existing sensor networks, Lack of official licences		Fully installed sensor networked as specified by you			Can you use it for the heating system in your house? Or instead of barometer outside
31	Ease of use, Lack of maintanance requirement, Cost (estimated around 10 cents per node), Flexibility in usable sensors		Not being able to use digital sensors, Limited lifespan, Limited in-operation adaptation options, Unproven technology, Possibility of premature degrading, Cost, Lack of distributed computing capabilities (nodes can only send data), Measurem		Plans to make nodes and the devices to do so		Nothing interresting at the moment	

			ent quality, Compatibility with existing sensor networks, Lack of official licences					
32							Sorry, you lost me.. Not your fault, I just am not interested enough in these kind of technical things to really try to understand what it is you are actually saying, I guess. I didn't even really get the part what it is. Why I entered..? Because of the word 'biodegradable'. That really sounds good to me.. That sounds like the right track to me. Good luck with your research.	