Nanocellulose from Harvesting Residues
Innovative Strategies to Advance the Sustainable Use of the Amazon Forests

The challenge

The Amazon forest is subjected to significant deforestation caused mainly by the inefficient utilization and management of the biomass resources there. Massive amounts of biomass are harvested every year. Only 41% of the harvested forest biomass is valorized while the major part is either burnt or left in site. With the current harvesting practices, 20-50% of the harvested wood is left in the harvesting sites leading to increased damages in case of fire and introducing more disturbance to the ecosystems there. Another problem is that most of the extracted wood ends up being used for timber (about 70%) while a minor part goes for the production of higher-value materials such as laminates and wood composites.

Nanocellulose-based materials are very promising for wide range of applications from construction to automobile industry to tissue engineering. Recently, there has been extensive research in the area of nanocellulose production from wood and its utilization in applications because of their interesting properties such as light weight and high strength. Such high value materials can be produced using the right technologies from the low-value wood residues. Nanocellulose could bring strong economical advantages to the utilization of biomass resources in the Amazonian region.

There are some challenges that need to be overcome to introduce a competitive business compared with the currently available ones in the Amazon forest. The Nanocellulose should be easily and locally produced within an optimum and sustainable supply chain, and can finally be transported economically to the market.

Our approach

We proposed to strengthen the position of the current operating forest enterprises by investigating possible strategies and technologies to make high use of the harvesting residues from supply chain procedures to high-value material production. Such strategy aims to vitalize the Amazonian region with new economic and employment opportunities.
The project started with designing a highly sustainable forest management at the Amazon region by optimizing the chain supply of the residues from the harvested forest biomass, which takes into account the current constrains of real road systems and resource locations. The design is conducted on two sites from the forestry enterprise stakeholder (ORSA Group Company). In the first step, the existing harvesting technologies for collecting and providing the wood residues of reduced impact logging operations in the Amazon region were evaluated and in the second step, the volumes of the harvesting residues were quantified.

The second part of the project focused on developing environmentally-friendly technologies for the production of nanocellulose from the harvesting residues at the Amazon region. Ionic liquids have been proposed as extraction solvents because of their green properties and their remarkable wood dissolution efficiency. An extraction procedure has to be achieved to extract the cellulose in their native state. The ionic liquids are selected according to their dissolving and swelling capacity in order to preferentially dissolve hemicellulose and lignin and favor cellulose swelling for more efficient defibrillation. The proposed process includes two steps; native cellulose isolation from the harvesting residues and nanocellulose production by efficient low-energy defibrillation of the extracted native cellulose.

Our conclusions

Starting with the sustainable forest management part of the project, the amounts of the harvesting residues were quantified with the help of ORSA Group. It was established that the most abundant species was the *Macaranduba* with 33 % of individuals, followed by the *Cupiiba* with 14 % (see Figure 1).

![Figure 1. The species commercially used on the study site in the Amazon region and their shares on the total volume.](image)

For the quantitative assessment of biomass, in order to obtain information of the available residues (trunk and branches), the volumes estimated for commercial wood and the volume of crowns of trees selected during the forest management were quantified, as well as the volume of the species that fall down together with the main tree during the harvesting operation (by-fellings). The total harvesting volume according to the forest management plan is about 32.86 m³/ha in a rotation period of 30 years. This value is focused on the commercial volume of stem wood intended for the utilization in the sawmill, resulting in a use of a little bit more than 1 m³/ha/yr.

![Figure 2. The commercially used volume of the harvested trees at the area of investigation in the Amazon regions.](image)

Using the biomass expansion factor of the FAO for estimating the biomass, an additional volume of 22.5 m³ of crown slash is left in the area. This volume is completed by a volume of around 9 m³ of unwanted by-fellings, resulting in a sum of 31.5 m³/ha of biomass which is not used for any other products. Figure 2 shows the contribution of the wood species in the calculated amount.

The proportion of the woody residues from the logging operations in sawmills of the Amazon region was also evaluated. The valorization of these residues is of major interest as their proportion in the sawmills is quite high, mainly due to a lack of technological conditions. Figure 3 shows the amount of residues for different assortments within the investigated sawmills.

![Figure 3. The amount of residues of different sawmilling assortments at the investigated sawmills.](image)

Talking now about the nanocellulose production technology, two ionic liquids were investigated. 1-ethyl-3-methylimidazolium acetate ([EMIM]OAc) and 1-butyl-3-methylimidazolium acesulfamate ([BMI]Ace). Acetate-based ionic liquids have been used widely for wood processing and fractionation while acesulfamate-based ionic liquids have been recently proposed as potent organosolv pulping agents for wood. It was noted that 1-butyl-3-methylimidazolium acesulfamate could selectively dissolve lignin in eucalyptus and radiata pine without causing any degradation to cellulose. This suggested that such ionic liquids might be particularly suited for direct production of nanocellulose.
In the first study, the molecular scale interactions between wood polymers and the selected ionic liquids were investigated. Wood cubes were swollen by each ionic liquid at various temperatures until saturation according to the international standards ISO4469 and ISO4859. The kinetics of the radial, tangential, and volumetric swelling were monitored as shown in Figure 4.

![Figure 4. The swelling behavior of wood in the ionic liquid [BMIM]Ace at 120 °C.](image)

At certain swelling degrees, the viscoelastic behavior of the swollen wood has been studied. A drop in the glass transition temperature (Tg) of lignin was observed by the action of the ionic liquids, as measured in Figure 5. [EMIM]OAc showed better swelling and softening efficiency compared to [BMIM]Ace, which also showed very strong wood hardening after certain amount of treatment time. The acetate-based ionic liquids showed that they can soften wood significantly at low temperature and after short amount of time. This softening behavior is very crucial to monitor the energy input required for the isolation of cellulose fibers from wood.

![Figure 5. The viscoelastic behavior of swollen wood in ionic liquid as measured using DMA.](image)

The swelling behavior of wood cubes by time using [EMIM]OAc is shown in the Figure 6.

![Figure 6. The swelling of wood cubes using [EMIM]OAc.](image)

In the second study, we aimed at assessing the potential of 1-butyl-3-methylimidazolium acesulfamate ([BMIM]Ace) for organosolv pulping of Norway spruce towards the production of Nanocellulose. In that objective, Norway spruce was treated with 1-butyl-3-methylimidazolium acesulfamate ([BMIM]Ace). The extracted material was precipitated while the residual wood was collected by filtration. Both residual wood and extract were characterized extensively with a wide range of analytical techniques. These analytical characterizations demonstrated that reactions others than pure delignification are at play when treating Norway spruce with ([BMIM]Ace).

In the third study, the acetate-ionic liquids were used for pulping. A dissolution and fractionation process was designed and optimized in order to get the maximum removal of lignin and hemicelluloses without degrading cellulose. Three fractions were isolated; native cellulose-rich residue, lignin-residue, and carbohydrate-lignin residue (see Figure 7). The acetate-ionic liquids seemed very promising as potent pulping agents.

![Figure 7. Two fractions separated after wood dissolution in [EMIM]OAc.](image)

**Our recommendations**

We recommend that our proposal is more applicable to large forestry enterprises and not to small scale cultivators. We also recommend that nanocellulose production must be combined with some wood pretreatment steps in order to reduce the high cost of the process resulted from the high cost of the ionic liquids. Finally, we recommend that the future studies do not only focus on nanocellulose production but more on the production of high value composite materials from wood.
Our impact

The project has tackled different topics related to forest biomass management and valorization. It confirmed that there are significant amounts of wood harvesting residues that could be valorized and hence would be used to start up new businesses based on these low cost amounts as starting materials. It has also demonstrated the possibility of the use of ionic liquids as green solvents for the fractionation of wood constituents in order to isolate cellulose fibers with an ultimate goal of producing high value nanocellulose.

In September 2012, we organized a workshop in Rio de Janeiro in order to set up a communication atmosphere for understanding how a nanocellulose production business could serve the small communities in the Amazon. A representative group from the Amazon communities has joined us and we discussed various points regarding their expectations from any newly-introduced technologies and what we can offer them on the real ground from the project side. Unfortunately, we concluded that our proposed technology could not be perfect to serve their needs and it could be only limited to big enterprises.

The results of the investigation of biomass residues and harvesting processes showed a significant amount of wood, which could be used for the proposed nanocellulose production or other industrial usages. The study sites revealed that there are a few tree species relevant for commercial use, but the skidding of big crowned trees is quite difficult in these densely grown stands. Therefore, a focus has been set to the residues at sawmills. These residues are already concentrated at one specific place and ready for further use. However, as mentioned earlier, the local population uses the residues for charcoal or firewood and is often not interested in use of higher technology instead of using wood for daily life routines.

The project has had also a significant impact in the science community as we participated in many scientific conferences and we plan to publish about the ionic liquid technology. One planned article will tackle the chemical interaction between ionic liquids and wood polymers and the possibility of side reactions taking place during the extraction of cellulose fibers from wood using ionic liquids. A second article will bring a better understanding of the in situ interaction between the molecules of ionic liquids and wood polymers and its influence on the energy input in the cellulose extraction process using ionic liquids. A third article will be about the optimization of tropical wood pulping using ionic liquids with complete fractionation process in order to valorize not only cellulose but also other wood polymers, which could bring more business opportunities and open extra doors for scientific advancement. Such publications would bring a significant contribution to the science literature and can serve a concrete ground for any future work on cellulose extraction from wood using ionic liquids.

Finally, the research stays of Brazilian students at the University of Freiburg and of the German students in various Brazilian universities have allowed large gains in transnational education and cultural awareness. The participants have been educated on particular aspects of deforestation in the Amazonia and on possible valorization routes of biomass waste streams to help fight these problems. As future key players in the Forestry Industry and in the Materials Industry, the participants should further impact the sector in which they will pursue their activities, with this newly gained awareness.

Our output

Conference Talks:


