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Biomass and Bioenergy 30 (2006) 316–320

BIOMASS & BIOENERGY

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# How to recover more value from small pine trees: Essential oils and resins

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Received 1 November 2003; received in revised form 11 May 2004; accepted 1 July 2005
Available online 10 January 2006

**Abstract**

In recent years, the young dense forests of northern Arizona have suffered extreme droughts, wildfires, and insect outbreaks. Improving forest health requires reducing forest density by cutting many small-diameter trees with the consequent production of large volumes of residual biomass. To offset the cost of handling this low-value timber, additional marketing options for current operations are urgently needed to recover more value as wood products, energy, and chemicals. Northern Arizona forests are predominantly composed of ponderosa pine (*Pinus ponderosa*) which, besides producing abundant timber, can also yield many useful chemicals such as essential oils and resins.

We describe a case study to assess the opportunities, constraints, and information required to integrate recovery of essential oils into forest and mill operations as might be used in northern Arizona. Preliminary results support the proposition there is an available, large supply of biomass with high concentrations of essential oils. The chemistry and process engineering for recovering these essential oils by distillation are well known. The potential output and uses also appear attractive given the substantial United States market for such products. However, less is known of the capability of essential oils extracted from ponderosa pine to compete with products imported from other countries. A more detailed assessment of product uses and further analysis of viable markets and environmental benefits are justified.


*Keywords:* Essential oils; Volatile oils; Resins; Pine oil; Pine needle oil; Resource recovery; Chemicals

## 1. Introduction

In recent years, the young and dense ponderosa pine forests of northern Arizona have suffered extreme droughts, wildfires, and insect outbreaks [1]. To restore these forests to an ecologically sustainable condition a large number of small-diameter pine trees must be felled. Whether the operation is for salvage or fuel reduction, large volumes of timber and slash would be generated. The economic value of small-diameter pine as timber, however, does not offset capital and operation costs of handling and processing. Options for overcoming this constraint include recovering more value from the biomass as energy, wood products from larger diameter trees, and chemicals. Advanced timber manufacturing processes can produce engineered lumber, beams, and sheets from small dimension stock. Heat and power can be generated by combustion; hydrocarbons can be produced in a reformer; and other chemicals produced with pyrolysis. An often overlooked opportunity of integration with wood and energy production is the steam distillation of volatile, essential oils—specifically pine oil and pine needle oil [2].

The predominant forest species of northern Arizona is ponderosa pine. Although historically the species had been tapped for resin, its recent and important uses are lumber and pulp. In addition to cellulose, ponderosa pine trees synthesize numerous, secondary, complex, organic compounds. These compounds in foliage, bark, and bole are used by the tree for growth, reproduction, and defense. They include essential oils, resins (rosin, fatty acids and fatty acid esters), and terpenes that can be extracted from

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0961-9534/$ - see front matter 
doi:10.1016/j.biombioe.2005.07.009

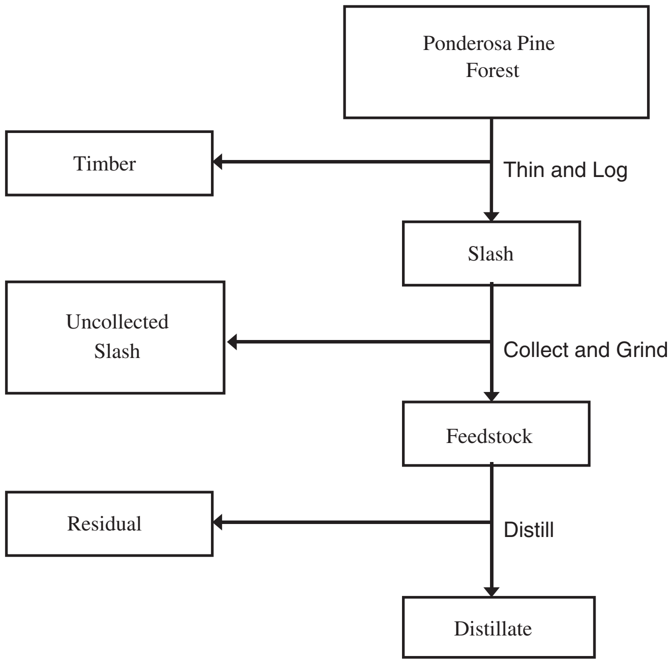


Fig. 1. Schematic diagram for recovering essential oils by distillation from small-diameter trees. The process illustrates that a portion of the slash from thinning and logging would be collected, ground, and distilled. Distillation separates the essential oils from a residual which may be used for bioenegery production.

slash and milling waste (Fig. 1). These compounds have many, high-value commercial uses such as industrial and household cleaning products, disinfectants, solvents, fragrances, medicine, and aromatherapy.

In this paper, we propose two scenarios and four assessment criteria for integrating the recovery of essential oils into forest operations in northern Arizona. Using currently available technology, recovery could occur either in the forest with mobile distillation units and/or at a mill site for wood products and energy. Assessment of potential benefits and constraints depend on information and research results for (1) resource supply, (2) chemistry and distillation process design, (3) economics and social values, and (4) ecological and environmental issues. This assessment provides a guide for detailed plans to recover more value from small trees by integrating distillation of essential oils into a community strategy for forest management and economic development. Although we use northern Arizona as a specific example, the concept can be adapted to other situations depending on market circumstances.

## 2. Resource supply—biomass and essential oils

### *2.1. There is a large and sustainable supply of foliage, twigs, bark, and wood residue*

Northern Arizona, specifically portions of the Coconino Plateau and White Mountains, supports an extensive and productive ponderosa pine forest of approximately one million hectares [3]. Reproduction of pine in the past century has been sufficient to result in dense stands of suppressed growth and small trees. The climate, soils, topography, ownership, history of commercial logging, and present need for improved forest health and wildfire fuels reduction allow for good operability, ease of access, and coordination among stakeholders. Timber sales for 2002 from three national forests in the region exceed $3.6 \times 10^6\,m^3$ and small trees (~12–22 cm diameter at 1.4 m height) comprise 50 percent of that timber volume [4]. This harvested, small-tree timber weighs approximately 157,000 tonnes (at 12 percent moisture content). Associated with this harvested timber (bole wood) is a sustainable supply of foliage and branches (slash) and bark. Foliage and branches constitute an additional weight equaling 50–77 percent of bole wood depending on tree size (Table 1). The 2002 harvest in northern Arizona alone would have generated a minimum of 236,000 tonnes of slash that could have been utilized for recovery of essential oil, but instead was piled in the forest and burned. For the region it is estimated that slash density approximates 0.5 tonnes $ha^{-1}$ (Table 1) [3].

Table 1
Distribution of biomass removed during thinning at the Northern Arizona University Centennial Forest, 2003 (unpublished data provided by J. Bailey)

| Diameter class (cm) | Bole wood | Slash | Slash produced per unit of bole wood (%) |
|---|---|---|---|
| | ($kg\,ha^{-1}$) | | |
| 5–15 | 54 | 81 | 150 |
| 15–25 | 1532 | 2654 | 173 |
| 25+ | 1376 | 2431 | 177 |
| Total | 2961 | 5167 | 175 |

Note: Slash includes foliage and branches.

### *2.2. There is a significant concentration and variety of essential oils and resins in ponderosa pine*

Essential oils are the volatile, aromatic oils, that is terpenes and oxygenated derivatives, produced by steam or hydro distillation of any part of a conifer tree. These are present at concentrations of 1–2 percent by weight, with higher concentrations in needles, twigs, and buds [5]. Pine oil refers to the distillate from any portion of the tree; pine needle oil refers to the distillate from only needles, twigs, and buds. The specific compounds of pine needle oil (Table 2) include $\alpha$-pinene, $\beta$-pinene, limonene, camphene, careen, myrcene, and over 60 other compounds [6]. The concentration and composition of essential oils vary by source, region, and season [5]. Because pines of northern Arizona range in elevation from 1500 to 2500 m, their quantity and quality of essential oils is expect to compare with that of high-latitude pines used in commercial markets. However, specific analysis is required.

Table 2
Components of pine needle oil from ponderosa pine (adapted from [5])

| Compound | Percentage | Usage |
|---|---|---|
| β-Pinene | 45.7 | Pharmaceutical |
| α-Pinene | 10.2 | Fragrance |
| 3-Carene | 8.4 | Manufacture of menthol |
| Estragole ( = methyl chavicol) | 8.0 | |
| α-Cadinol | 2.7 | |
| Limonene + β-Phellandren | 2.4 | |
| τ-Cadinol + τ-Muurolol | 2.0 | |
| Myrcene | 1.4 | Insect attractant |
| α-Terpineol | 1.4 | Perfume and household products |
| Terpinolene | 0.8 | Flavoring food and enhancing fragrance |
| γ-Cadinene | 0.9 | |
| Methyl eugenol | 0.6 | Pesticide and insect attractant |
| (ζ)-*trans*-α-bergamot | 0.6 | |
| Veridiflorol | 0.6 | |
| Camphene | 0.5 | Manufacture of synthetic camphor |
| *cis*-Ocimene | 0.5 | |
| Spathulenol | 0.5 | |
| α-Muurolene | 0.5 | |
| Santene | 0.2 | |

In 1910, large-scale experiments of resin tapping were conducted on ponderosa pine of the Coconino Plateau [7]. Results indicate the yield of turpentine from northern Arizona is comparable to the average for sites in the southeastern pine forest of the United States. Although northern Arizona is not presently a commercial source for turpentine and resins (naval stores), there is a potential and opportunity to include resin production along with recovery of essential oils. The world importance of these and other non-wood forest products have been well reviewed [2].

## 3. Recovery process and integration

### *3.1. The chemistry and process engineering of distillation to recover essential oils is well developed*

Essential oils and the residual biomass are separated by distillation. Although essential oils may be extracted in a water distillation process, long contact leads to degradation or hydrolysis avoided by steam distillation. The basic process of steam distillation is to (1) generate steam in a separate vessel, (2) pass steam through ground plant material to volatilize and strip off the oils, (3) cool and condense the steam and oil vapors into liquid form, and (4) decant the lighter immiscible oils from the water [8,9]. The efficiency or ratio of product mass to input mass (pine needles) ranges from 0.3 to 1.8 percent [10]. Specific research is necessary for northern Arizona to determine efficiency ratios, but for the current analysis, it is conservatively estimated to be 0.5 percent or less. Neither very high temperatures nor pressures are required in the distillation process. Required equipment is either commercially available or easily designed and manufactured. Additional research and development, however, is needed to adapt the process for materials and conditions of northern Arizona to ensure quality and consistency of output (for example, avoid hydrolysis, polymerization, or decomposition).

In terms of integrating the distillation process into the removal of biomass from forests in northern Arizona, the specifics of the distillation chemistry and engineering vary by application scenario. A forest-thinning operation might be optimized for use of foliage and small branches in the production of pine needle oil at the log loading site. The harvest systems used to move the slash to the loading site is an important consideration in cost efficiency and product recovery. Other key elements include the type of distillation system used, and whether it would be located at the loading site or in a centralized location receiving slash from many forest sites. For production of pine oil, co-location with a wood products manufacturing operation might also be optimized for use of large amounts of sawdust and wood waste. Additional cost considerations and coordination are required for the transportation of raw material (slash or sawdust) for distillation operations not adjacent to a raw material source.

The use of the residual material for further value-added purposes after the distillation process is also an important consideration. One option not previously assessed in this context is bioenergy. Although extraction of essential oils may reduce the heat of combustion of residual material by 5–10 percent [11], burning this "lean" biomass for the purpose of bioenergy could be cleaner, that is non-sooty. Additional research and development is needed to design particular specifications for either an in-woods or co-location scenario and to determine the realized efficiency of recovery and the environmental benefits of cleaner bioenergy.

## 4. Economic and environmental considerations

### *4.1. The product potential of essential oils in northern Arizona is significant*

Although there still remain many unknowns in the supply of material available for recovery, the harvesting systems and transportation of raw material, in the concentration of essential oils in that material, the efficiency of recovery, and particularly in market prices and competition, we can illustrate product potential. For this estimate, we assume only 50 percent of the slash produced in small-diameter trees during the 2002 northern Arizona harvest (see above) is utilized for recovery. We further assume a conservative estimate of recovery efficiency of 0.5 percent of processed slash (including needle and twigs). The resulting amount of essential oil produced is 590 tonnes. If only half of the residue chips from milled logs were also processed, an additional 137 tonnes would be obtained.

In 2003, the United States imported more than 600 tonnes of pine oil, mostly from China [12]. An additional 5,000 tonnes of pine oil was exported [12]. Reliable retail prices for pine oil were not available, but the retail sale price for comparable oils from other conifers ranged from $5 to $8.66 per 10 ml in 1999 [13]. Assuming that the oils extracted from ponderosa pine in northern Arizona are similar in composition and product potential as those imported and exported, it would appear that the market potential could be substantial. Further assuming a wholesale discount rate of 60 percent [13] for retail prices of $5 per 10 ml, the unrealized market value of ponderosa pine oil is approximately $300,000 per tonne. If a viable market existed for the more than 700 tonnes of pine oil extracted from northern Arizona slash and sawdust in 2002, gross value would have been more than $200 million (US$) not including production costs.

Several factors, however, dictate market viability. The least of which is the ability of ponderosa pine oil to compete in the marketplace with similar products. Common uses are as ingredients in cleaners, disinfectants, solvents, fragrances, medicines, aromatherapy, and as raw materials for downstream chemicals like synthetic camphor. Key cost nodes included in the production of these products are (1) harvesting, transportation, and purchasing of the forest slash and milling residue, (2) production costs associated with steam distillation, (3) production costs associated with secondary processing, and (4) marketing and distribution of the finished products. Within each of these production steps there are an assortment of costs that will needed to be quantified with additional research. Other factors influencing market viability include the quality of products generated. Are essential oils extracted from ponderosa pine a viable substitute for existing products at a comparable price? Are there chemical properties or recovery efficiencies unique to ponderosa pine in northern Arizona that make it economically competitive? Opportunities to penetrate established markets requires further study. Additional research is also needed to investigate properties for controlling fungi and insects and other product uses that may be unique to ponderosa pine.

### *4.2. There are social and environmental benefits from integrating essential oil recovery into forest and manufacturing operations*

The primary incentive for essential oil recovery remains to help offset the high costs of forest thinning and wildfire fuel management in stands of small-diameter ponderosa pine. Community safety is improved by reducing the occurrence and damage from extreme fires. Desirable employment opportunities may also be provided if pine oil from northern Arizona becomes economically viable to process. There are also potential environmental benefits. Toxic levels of mercury can be emitted from the combustion of slash and litter in prescribed and naturally-occurring forest fires [14]. A program such as proposed allows for better control of mercury pollution. Slash and manufacturing wastes processed by commutation and removal of essential oils (“lean slash”) are expected to have different rates and pathways of decomposition once they are returned to the soil. The consequences of altered recycling and effects on the soil biota require additional research.

## 5. Conclusion

Integrating recovery of essential oils by steam distillation into a program of forest thinning and biomass utilization may be an attractive option for improving forest and economic health in northern Arizona. Although data presented in this note are preliminary and economic values assume unlimited market entry, they are sufficient to identify several important information and research needs and to justify a more detailed assessment and continued development of the concept.

## Acknowledgments

We thank Professors John Bailey and Robert Larson, Northern Arizona University, School of Forestry for use of their valuable data. Dana Erickson, USDA Forest Service, Rocky Mountain Research Station, provided necessary assistance with laboratory work.

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