American Forest & Paper Association

April 6, 2026

Department of the Treasury
Internal Revenue Service
CC:PA:01:PR (REG-121244-23)
Room 5503
P.O. Box 7604, Ben Franklin Station
Washington, D.C. 20044

Submitted via regulations.gov

Re: Section 45Z Clean Fuel Production Credit (RIN 1545-BR30), 91 Fed. Reg. 5160 (February 4, 2026)

The American Forest & Paper Association ("AF&PA") appreciates the opportunity to comment on the proposed rule ("Proposal" or "Proposed Rule") of the Department of the Treasury and the Internal Revenue Service ("Treasury") to implement the clean fuel production credit under section 45Z of the Internal Revenue Code. As outlined below, we would like to highlight the following key points.

- **We urge Treasury to determine in its final rule and Annual Table that transportation fuels produced from byproducts of pulp and paper manufacturing such as tall oil, methanol, bark, and lignin are qualified with an emissions rate of not greater than 50 kg CO2e/mmBTU. (pp. 6-8)**

- We support Treasury's determination in the proposed regulations to not include electricity in the definition of "transportation fuel." (pp. 8-10)

I. Background

A. Introduction

The American Forest & Paper Association (AF&PA) serves to advance public policies that foster economic growth, job creation and global competitiveness for a vital sector that makes the essential paper and packaging products Americans use every day. The U.S. forest products industry employs more than 925,000 people, largely in rural America, and is among the top 10 manufacturing sector employers in 44 states. Our industry accounts for approximately 4.7% of the total U.S. manufacturing GDP, manufacturing more than $435 billion in products annually. AF&PA member companies are significant producers and users of renewable biomass energy and are committed to making sustainable products for a sustainable future through the industry's decades-long initiative — *Better Practices, Better Planet 2030*.

B. Pulp and Paper Manufacturing Byproducts That Can Be Used as Transportation Fuel

Several pulp and paper manufacturing by-products are currently being produced and marketed as low carbon transportation fuels.[1] Examples include the following:

- Tall oil, which is produced from black liquor generated by the pulping of wood in the pulp and paper manufacturing process. A pulp mill can use the crude tall oil as process fuel or sell it to biorefineries or biofuel plants to process it into biobased products.[2]

- Methanol, which as part of the pulp and paper manufacturing process, is generated as a byproduct and can be extracted and refined to produce fuel

[1] Memorandum from Barry Malmberg, National Council for Air and Stream Improvement, to Jesse Levine and Paul Noe (AF&PA), Lifecycle Greenhouse Gas Information for Pulp and Paper Manufacturing Byproducts Suitable for Transportation Fuels at pp. 3-4 (2026).
[2] USDA. November 06, 2024. United States Tall Oil Exports to the Nordics Surge. Report Number: FI2024-0002 lists a number of biorefinery and biofuel producers in Finland and Sweden.

suitable for transportation purposes, and which has potential for use within the maritime sector.[3]

C. Overview of Fiber Supply for the U.S. Pulp and Paper Industry

Ninety percent of the wood that is used to produce the essential paper and wood products that Americans use every day is sourced from private, sustainably managed forestland. The majority of these lands are family owned.[4] For pulp and paper manufacturing, our forest fiber supply commonly is called pulpwood, which is roundwood from younger trees grown in sustainably managed forests, as well as sawmill residues.

Based on AF&PA's Annual Capacity & Fiber Consumption Survey of AF&PA members with U.S. pulp and paper mills, in 2024, roundwood and roundwood chips accounted for 91% of the pulpwood used to make pulp at U.S mills; manufacturing residues (e.g., sawmill chips) accounted for the remaining 9% of the pulpwood use.[5] For the purpose of AF&PA's Annual Capacity & Fiber Consumption Survey, roundwood is cut from trees in bolts or logs of four feet or longer and cut and purchased to a minimum diameter specified by the consuming mill and brought to the mill for chipping. Roundwood chips are chips made from roundwood as defined above but produced in the forest or at a remote chip mill, whether company-owned or not. Manufacturing residues include materials such as chips, slabs, shavings, sawdust etc. that are made during or left over from wood product manufacturing.

D. Forest Products Manufacturing Provides Far More American Jobs and Economic Benefits than Stand-Alone Bioenergy Generation

Studies have demonstrated that the use of forest biomass to create paper products and wood products (including associated renewable energy production) provides significantly more jobs and economic value than using biomass solely to produce energy:

---

[3] Memorandum from Barry Malmberg, National Council for Air and Stream Improvement, to Jesse Levine and Paul Noe (AF&PA), Lifecycle Greenhouse Gas Information for Pulp and Paper Manufacturing Byproducts Suitable for Transportation Fuels at p. 4 (2026).

[4] https://www.fs.usda.gov/managing-land/private-land

[5] AF&PA, 65th Annual Capacity & Fiber Consumption Survey (May 2025).

- A RISI Jobs Study[6] commissioned by AF&PA found that, for a given volume of wood consumption, the U.S. forest products industry sustains five times as many core jobs (i.e., mill jobs) and nine times as many total jobs in the supply chain (including logging, paper converting jobs, and downstream wood processing jobs) as stand-alone biomass energy production (electricity, wood pellets, and cellulosic ethanol). The RISI report also confirms the research done in Europe and Canada showing that the traditional forest products industry creates more employment for the same amount of wood consumed than the emerging bioenergy industry.[7]

- Likewise, a Poyry study commissioned by the Confederation of European Paper Industries (CEPI) estimated that the pulp and paper industry in Europe directly created six jobs for every job created by the bioenergy alternative, and the ratio rises to 13:1 if total employment (direct and indirect) is considered.[8]

- Another study concluded that there is a 4-fold to 10-fold greater value to the economy (product value, plus associated workers' purchasing power) from producing paper than burning wood for electricity alone.[9]

E. Section 45Z of the Internal Revenue Code

The 45Z clean fuel production credit applies to qualified facilities that produce transportation fuels suitable for use in a highway vehicle or aircraft and have a lifecycle emissions rate of not greater than 50 kg CO2e per mmBTU.[10] 45Z is a time-limited credit ending after December 31, 2029.[11] The value of the credit per facility is calculated according to a base amount of 20 cents per gallon or $1.00 per gallon if prevailing wage and apprenticeship requirements are met then multiplied by an emissions factor.[12] The emissions factor is the amount equal to the quotient of 50 kg CO2e per mmBTU minus the emissions rate for such fuel divided by 50 kg CO2e per mmBTU.[13]

---

[6] RISI Report. Jobs Creation in PPI and Energy Alternative in the United States. American Forest & Paper Association, 2010.
[7] RISI Report. *Jobs Creation in PPI and Energy Alternative in the United States*. American Forest & Paper Association, 2010.
[8] See Value Added and Employment in PPI and Energy Alternative, Poyry (Dec. 2006).
[9] See B.A. Thorp and Masood Akhtar, "The Best Use of Wood," Paper360 (Jan/Feb 2009).
[10] 26 U.S.C. § 45Z(a), (d)(4)-(5).
[11] 26 U.S.C. § 45Z(g).
[12] 26 U.S.C. §§ 45Z(a)(1)-(2), 45Z(b)(1).
[13] 26 U.S.C. § 45Z(b)(1).

Under the statute, the Treasury Secretary shall publish an annual table setting forth the emissions rate for similar types and categories of transportation fuels based on lifecycle greenhouse gas emissions as described in section 211(o)(1)(H) of the Clean Air Act expressed as kg of CO2e per mmBTU, which a taxpayer shall use to determine eligibility for this credit.[14] For non-aviation fuel, the emissions rate shall be based on the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model.[15] For sustainable aviation fuel, the lifecycle GHG emissions of such fuel shall be determined based on the most recent Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) or any similar methodology which satisfies the criteria under section 211(o)(1)(H).[16]

F. Treasury's Proposed Rule

On February 4, 2026, the Internal Revenue Service (IRS) and the Department of the Treasury proposed regulations[17] regarding the 45Z clean fuel production credit as amended by the One, Big, Beautiful Bill Act (OBBBA). Notable provisions in the proposed regulations include:

- **Emissions rate methodology and limits**
    - A taxpayer determines a fuel's emissions rate using either the annual emissions rate table published by the Secretary or a Provisional Emissions Rate ("PER") determination.[18] Transportation fuels other than sustainable aviation fuel (SAF) must use the annual emissions rate table derived from the 45ZCF-GREET model.[19] For SAF transportation fuel, taxpayers may use the 45ZCF-GREET model, or the most recent version of CORSIA Default or CORSIA Actual.[20]

- **PER petition procedures**

[14] 26 U.S.C. § 45Z(b)(1)(B)(i).
[15] 26 U.S.C. § 45Z(b)(1)(B)(ii).
[16] 26 U.S.C. § 45Z(b)(1)(B)(iii).
[17] 91 Fed. Reg. 5160 (Feb. 4, 2026).
[18] Prop. Treas. Reg. §1.45Z-2(d)(1), 91 Fed. Reg. 5160, 5196 (Feb. 4, 2026).
[19] Prop. Treas. Reg. §1.45Z-2(e)(3)(iv).
[20] Prop. Treas. Reg. §1.45Z-2(e)(3)(v).

- If a taxpayer produces an eligible fuel as defined in § 1.45Z-1(b)(12), and provided the taxpayer's type and category of fuel is not already covered in the emissions table, the taxpayer may request a PER—after first submitting an Emissions Value Request ("EVR") to DOE and subsequently receiving a calculated emissions value letter ("CEVL") from DOE.[21]

- **Indirect land-use changes**
  - For transportation fuel produced after 2025, emissions attributed to "indirect land use changes" must be excluded, consistent with OBBBA amendments.[22]

- **Definition of "suitable for use"**
  - Proposed regulations establish that a fuel is "suitable for use" if it has practical and commercial fitness for use in a highway vehicle or aircraft (or is blended into a fuel mixture that has practical and commercial fitness for use in a highway vehicle or aircraft); actual use as a fuel in a highway vehicle or aircraft is not required.[23]

- **Electricity not included in the definition of "transportation fuel"**
  - The proposed regulations do not include electricity in the definition of "transportation fuel."[24] So, therefore electricity production would be ineligible for the section 45Z credit.

II. We Urge Treasury in its Final Rule and Annual Table to Determine that Transportation Fuels from Byproducts of Pulp and Paper Manufacturing Such as Tall Oil, Methanol, Bark, and Lignin Are Qualified with an Emissions Rate of Not Greater than 50 Kg CO2e/mmBTU

AF&PA urges Treasury to determine in its final rule and Annual Table that transportation fuels produced from byproducts of pulp and paper manufacturing such as tall oil, methanol, bark, and lignin are qualified with an emissions rate of not greater than 50 kg CO2e/mmBTU. As noted in the attached NCASI technical memorandum, existing analysis

[21] Prop. Treas. Reg. §1.45Z-2(f)(1)-(5).
[22] Prop. Treas. Reg. §1.45Z-2(d)(3).
[23] Prop. Treas. Reg. §1.45Z-1(b)(34).
[24] Prop. Treas. Reg. §1.45Z-1(b)(34), (b)(19).

conducted in accordance with the EU Renewable Energy Directive (RED) has determined that several forest products industry feedstocks, including tall oil, methanol, bark, and lignin have a lifecycle GHG emissions rate of not greater than 29.7 kg CO2e/mmBTU.[25]

Under EU RED, this existing analysis relied upon a greenhouse gas accounting methodology that uses a lifecycle emissions GHG approach and includes emission contributions from the extraction or cultivation of raw materials, emissions from processing, emissions from transport and distribution, and emissions from the fuel in use. This methodology reflects a similar methodology to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and satisfies the criteria of section 211(o)(1)(H), as required by the statute for aviation fuel to qualify.[26]

Regarding fuels other than sustainable aviation fuel, we also recommend that Treasury and the U.S. Department of Energy incorporate the EU analysis and findings (as discussed above and in the attached NCASI memorandum) into the GREET model.

As noted above, under the statute, the Treasury Secretary ***shall publish an annual table setting forth the emissions rate*** for similar types and categories of transportation fuels based on lifecycle greenhouse gas emissions as described in section 211(o)(1)(H) of the Clean Air Act, expressed as kg of CO2e per mmBTU, which a taxpayer shall use to determine eligibility for this credit.[27] For sustainable aviation fuel, the lifecycle GHG emissions of such fuel ***shall be determined in accordance with*** the most recent Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) or ***any similar methodology*** which satisfies the criteria under section 211(o)(1)(H).[28]

We note that in guidance issued by the Biden Treasury Department, the 2025 Annual Table did not include emissions rate determinations, but rather simply directed taxpayers to the GREET model or CORSIA model for a range of fuels.[29] We respectfully submit that based on the best reading of the statute, the annual table shall set forth emission rates, not just a methodology for a taxpayer to calculate an emission rate, and,

[25] Memorandum from Barry Malmberg, National Council for Air and Stream Improvement, to Jesse Levine and Paul Noe (AF&PA), Lifecycle Greenhouse Gas Information for Pulp and Paper Manufacturing Byproducts Suitable for Transportation Fuels at p. 2 (2026).
[26] 26 U.S.C. § 45Z(b)(1)(B)(iii).
[27] 26 U.S.C. § 45Z(b)(1)(B)(i).
[28] 26 U.S.C. § 45Z(b)(1)(B)(iii).
[29] Treasury and IRS Notice 2025-11, 2025-6 I.R.B. 704 (released January 10, 2025).

for aviation fuel, that emission rate can be determined using ***any*** methodology similar to CORSIA and consistent with Clean Air Act section 211(o)(1)(H) as sufficient under the statute. Therefore, the provisions in the proposed regulations that require a taxpayer to model a fuel based solely on GREET or CORSIA are not needed for fuels that meet the statutory test based on similar methodologies.[30]

As discussed above and in the attached NCASI memorandum, pulp and paper mill byproducts such as tall oil, methanol, bark, and lignin easily meet the statutory test of having a lifecycle greenhouse gas emissions rate of not greater than 50 kg CO2e/mmBTU – and in fact have a lifecycle greenhouse gas emissions rate at about half of the statutory standard. Accordingly, Treasury should determine in the final rule and annual table that transportation fuels from byproducts of pulp and paper manufacturing such as tall oil, methanol, bark, and lignin are qualified for the 45Z clean fuel production tax credit and assign a specific emission rate(s) in the annual table consistent with the attached NCASI technical memorandum.

III. We Support Treasury's Determination in the Proposed Regulations To Not Include Electricity in the Definition of "Transportation Fuel."

In its proposed regulations to implement the 45Z credit, Treasury determined to not include electricity in the definition of "transportation fuel." So, therefore electricity production would be ineligible for the section 45Z credit. Treasury's reasoning for this determination includes the following:

1. Congress designed the 45Z tax credit to replace a range of incentives for liquid or gaseous fuels.[31]
2. Anti-stacking rules disallow receiving the 45Z credit and certain other credits for the same facility for a taxable year. Congress understood the potential for activity at a facility to generate multiple credits for a taxable and wished to foreclose that possibility.[32]

[30] Prop. Treas. Reg. §§1.45Z-2(e)(3)(v), 1.45Z-5(b)(3), 91 Fed. Reg. 5196-98, 5201-02.
[31] 90 Fed. Reg. 5168.
[32] 90 Fed. Reg. 5168.

3. The Internal Revenue Code already provides a separate credit for clean electricity production under section 45Y.[33]

Under section 45Z(d)(5)(A), the term "transportation fuel" is defined in relevant part as "a fuel which … is suitable for use as a fuel in a highway vehicle or aircraft, has an emissions rate which is not greater than 50 kilograms of CO2e per mmBTU, is not derived from coprocessing with an applicable material[34] (or materials derived from an applicable material) with a feedstock which is not biomass, and is not produced from a fuel for which a credit under this section is allowable."[35]

Treasury proposes to adopt this statutory definition as the regulatory definition as follows:

> Transportation fuel – In general. The term *transportation fuel* means, pursuant to section 45Z(d)(5)(A), a fuel that –
>
> (A) Is suitable for use as a fuel in a highway vehicle or aircraft;
>
> (B) Has an emissions rate which is not greater than 50 kilograms of CO2e per mmBTU;
>
> (C) Is not derived from coprocessing with an applicable material (or materials derived from an applicable material) with a feedstock which is not biomass; and
>
> (D) Is not produced from a fuel for which a credit under this section is allowable.[36]

We agree and support Treasury's determination to not include electricity in the regulatory definition of "transportation fuel". This interpretation could be an important

[33] 90 Fed. Reg. 5168.
[34] Under section 45Z(d)(5)(B), "applicable material" is defined to mean monoglycerides, diglycerides, and triglycerides, free fatty acids, and fatty acid esters.
[35] 26 U.S.C. § 45Z.
[36] 91 Fed. Reg. 5194.

guardrail against unintended adverse impacts to the reliability and affordability of the forest fiber supply for U.S. pulp and paper manufacturing.[37]

IV. CONCLUSION

We close by again expressing our appreciation to Treasury for the opportunity to comment on this important Proposed Rule. If you have any questions or would like further information, please feel free to contact Jesse Levine at Jesse_Levine@afandpa.org.

Best regards,

Paul R. Noe
Vice President, Public Policy

Attachment

[37] For example, a recent study from the Southern Forest Resource Assessment Consortium projects a 53% increase in woody biomass demand in the Southeast associated with use of woody biomass for energy supply and significant disruptions to fiber supply chains. These conclusions were based solely on nine bioenergy projects expected to come online in the coming years – not including impacts from any new policy changes.

NCASI
IMPACT. SCIENCE. SOLUTIONS.

National Council for Air and Stream Improvement, Inc.

APRIL 6, 2026

TO: Jesse Levine and Paul Noe (AF&PA)

FROM: Barry Malmberg Ph.D., Director – Sustainability

CC: Kirsten Vice and Adam Costanza (NCASI)

SUBJECT: Lifecycle greenhouse gas information for pulp and paper manufacturing by-products suitable for transportation fuels

Regulations are being proposed for determination of clean fuel production tax credits[1]. These proposed regulations include information on eligibility requirements for transportation fuels. To qualify "Under section 45Z(b)(1)(A), a transportation fuel's emissions factor measures the reduction in a fuel's emissions rate, expressed as kg of CO_2e per mmBTU, relative to the statutory baseline emissions rate of 50 kg of CO_2e per mmBTU, expressed as a fraction of the statutory baseline. Expressed mathematically, the emissions factor calculation is as follows: (50 kg CO_2e per mmBTU - emissions rate) ÷ 50 kg CO_2e per mmBTU."[2] The emission rate is calculated via a comparative lifecycle GHG emission approach, i.e. considering emission sources and sinks along the full value chain of the product with comparison to a baseline emission number, two approaches (45ZCF–GREET model[3] and CORSIA[4]) are listed as appropriate methodologies, and for aviation fuel any methodology similar to CORSIA and consistent with section 211(o)(1)(H) may be used. A transportation fuel with an emission rate of 50 kg CO_2e per mmBTU or less would qualify for 45Z tax credits. Currently, no forest product industry derived pathways are included in the 45ZCF–GREET model. "Forestry residues" are listed as a fuel feedstock to generate CORSIA eligible fuels via a number of conversion processes within the CORSIA framework[5]. This memo reviews the production of several pulp and paper manufacturing by-products (tall oil, turpentine, and methanol) that are potentially suitable for transportation fuels. The applicability of tall oil, turpentine, and methanol as low carbon transportation fuels within the EU Renewable Energy Directive (RED) program, which uses a

[1] https://www.federalregister.gov/documents/2026/02/04/2026-02246/section-45z-clean-fuel-production-credit

[2] The term "mmBTU" means 1,000,000 British thermal units, and the term "BTU" means British thermal units. The term "CO_2e" means, with respect to any greenhouse gas, the equivalent carbon dioxide (as determined based on relative global warming potential)

[3] Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model developed by the Department of Energy https://www.energy.gov/cmei/fuels/articles/us-department-energy-releases-45zcf-greet

[4] Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). https://www.icao.int/CORSIA

[5] CORSIA default life cycle emissions values for CORSIA eligible fuels https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Eligible%20Fuels/ICAO-document-06-Default-Life-Cycle-Emissions-November-2025.pdf

similar comparative lifecycle GHG emissions approach for determination of eligible fuels as the proposed 45Z regulations, is reviewed.

Based upon lifecycle GHG emission results using the EU Renewable Energy Directive framework, biomass derived transportation fuels such as tall oil, methanol, and turpentine have GHG emission rates much less than the 50 kg CO_2e/mmBTU 45Z standard. It is recommended that work be undertaken to incorporate these fuel pathways into DOE's 45ZCF-GREET model so that the GHG reduction benefits of forest products industry derived transportation fuels be recognized.

Existing analyses of forest products industry biomass residuals and by-products used as fuels: EU Renewable Energy Directive (RED)

The EU Renewable Energy Directive is a legal framework for the promotion and development of renewable energy across all sectors of the EU economy, including the transportation sector. RED was originally established in 2009 (Directive 2009/28/EC RED I)[6] and has been modified and expanded over time; Directive 2018/2001 (RED II)[7] and Directive 2023/2413 (RED III)[8]. RED II provides detailed information on the methodology for the calculation of greenhouse gas emissions from the production and use of transport fuels, biofuels and bioliquids.[9] The greenhouse gas emissions accounting methodology uses a life-cycle emissions GHG approach, and the methodology includes emission contributions from the extraction or cultivation of raw materials (e_{ec}), annualized emissions from carbon stock changes caused by land-use change (e_l), emissions from processing (e_p), emissions from transport and distribution (e_{td}), and emissions from the fuel in use (e_u).. Similar to the proposed 45Z regulations, renewable liquid and gaseous transport fuels are compared to a baseline fossil fuel comparator, which is currently 94 g CO_2eq/MJ.[10]. The stringency of the greenhouse gas emission savings threshold increases over time. To qualify as a recycled carbon fuel, the fuel must meet or exceed the minimum greenhouse gas emission savings threshold of 70 % compared to the fossil fuel comparator, i.e. must not exceed 28.2 g CO_2e per MJ (29.7 kg CO_2e per mmBTU). Current forest products industry feedstocks that are listed within RED II as qualified feedstocks include[7]: Tall oil pitch; biomass fraction of wastes and residues from forestry and forest-based industries, namely, bark, branches, pre-commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil; other ligno-cellulosic material except saw logs and veneer logs, and raw methanol from kraft pulping stemming from the production of wood pulp (included in the amendment to Directive EU 2018/2001.[11]). Companies undertake the process of validating fuels. Tall oil (listed under Crude tall oil (CTO) or Tall oil pitch , sulfate turpentine (listed under Crude sulphate turpentine (CTS)), and methanol (listed under Raw methanol) from wood pulp all have valid certificates within the International Sustainability & Carbon Certification program (ISSC)[12]. Some forest products industry companies are actively producing and marketing low carbon transportation fuels and making GHG reduction claims based upon the RED methodology, e.g., UPM's BioVerno diesel "Over 80% less greenhouse gas emissions than fossil diesel" and naphtha

[6] https://eur-lex.europa.eu/eli/dir/2009/28/oj/eng
[7] https://eur-lex.europa.eu/eli/dir/2018/2001/2018-12-21/eng
[8] https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1185
[11] https://eur-lex.europa.eu/eli/dir_del/2024/1405/oj/eng
[12] ISCC is among the world's largest certification systems. https://www.iscc-system.org/certification/certificate-database/valid-certificates/

products[13], and Sunpine's Raw Tall Diesel "According to current regulations, Sunpine's Raw Tall Diesel has a carbon dioxide reduction value of up to 99 percent."[14]

Background on pulp and paper manufacturing by-products and use as biofuels: production of turpentine, tall oil, and methanol in kraft pulping

Turpentine, tall oil soap, and methanol are by-products of the kraft pulping and recovery process and are primarily extracted at different points in the process (Figure 1 for a kraft pulp mill)[15]. Crude sulfate turpentine is removed in the digester area while crude tall oil and crude methanol are removed in the black liquor evaporation area. After additional refinement, turpentine, tall oil, and methanol all have potential as low carbon transportation fuels.

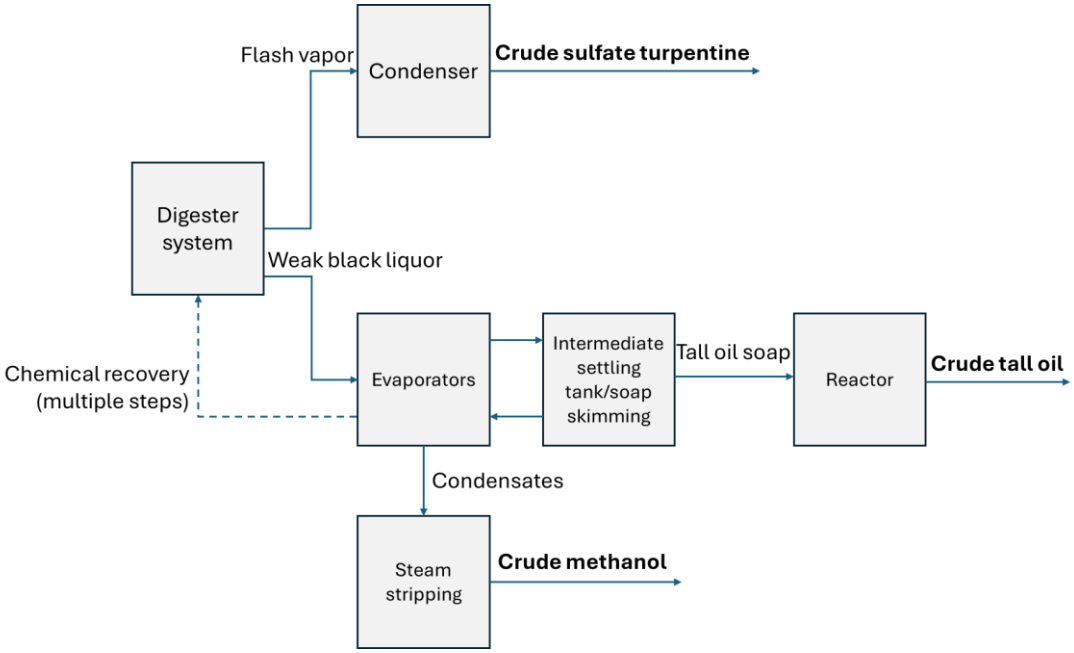

Figure 1. Simplified schematic of typical extraction points for crude sulfate turpentine (CST), crude tall oil (CTO), and crude methanol (CST and CTO are predominantly produced from pine species; methanol is generated from both softwood and hardwood species)

Tall Oil[16]

Tall oil soap is a direct by-product of the kraft pulping process, with the highest generation amounts from the kraft pulping of pine wood (*tall* is Swedish for pine). Rosin and fatty acids, naturally present in the wood, are saponified with the kraft cooking liquor to form alkali salts or soaps in the kraft black liquor. The tall oil soap separates naturally from black liquor and is removed by skimming in black liquor tanks. Tall oil skimming typically occurs at black liquor solids concentrations of ~25-35%, where the separation is

[13] https://www.upmbiofuels.com/traffic-fuels/
[14] https://www.sunpine.se/en/products/ratalldiesel/
[15] Turpentine can be extracted at mechanical pulp mills (Beca AMEC Limited 2006) and methanol is produced in other mill types such as semi-chemical mills (Venkatesh et al. 1997).
[16] Tall oil is a generic name for a number of products obtained from the manufacture of wood pulp by the alkali (sulfate process), more popularly known as the kraft process. Tall oil and tall oil products are defined by where in the refinement process the material is obtained, and products include tall oil soap, crude tall oil, acid refined tall oil, distilled tall oil, tall oil fatty acids, tall oil rosin, tall oil heads, and tall oil pitch (ASTM 1972, updated in 2022)

most effective (Dogaris et al. 2019). Black liquor soap skimmings is a complex mixture consisting of hundreds of different types of rosin and fatty acids, and the relative predominance of acid types is dependent on wood species, location, climate, and pulping conditions (Huibers 2000). Crude tall oil is formed by acidulation (typically with sulfuric acid) of tall oil soap skimmings, and is a dark brown liquid mixture of fatty and rosin acids, and neutral materials. Crude tall oil yields typically range from 15-50 kg CTO/mt pulp (Huibers 2000). Crude tall oil can be further refined via distillation and can be refined into a form suitable as a replacement to fossil transportation fuels, with some companies currently producing commercial tall oil-based transportation products and marketing these products as low carbon transportation fuels in the European market.[17]

Sulfate Turpentine

In a kraft digester, wood chips are heated with steam in a solution of sodium hydroxide and sodium sulfide. Vapor containing steam and turpentine is separated from pulping liquor in flash tanks that are part of the digester system. The vapor is condensed via heat exchange to produce a mixture of water, turpentine, and sulfur compounds, and this mixture is gravity decanted to separate turpentine. Sulfate turpentine is comprised of a variety of volatile oils naturally present in trees. Pine species typically have the highest generation rates of turpentine, with yields of up to 4 liters turpentine/mt of pulp (Beca AMEC Limited 2006). Yields are dependent upon tree species, geographical location, and method of extraction.

Methanol

Methanol is generated from reactions of methoxyl groups present naturally in lignin and hemicellulose with sodium hydroxide during cooking in the digester (Zhu et al. 2000). Methanol generation rates at US kraft mills are about 11 kg methanol/mt of pulp (NCASI 1997; Venkatesh et al. 1997). Methanol generation is influenced by wood species (with pulping of hardwood generally producing more methanol than softwoods), digester pulping time and conditions (with high alkali charge, high cooking temperature, and longer cooking time generally increasing methanol generation), and production type (Zhu et al. 2000). Methanol is most concentrated in black liquor evaporator foul condensates and can be removed via steam or air stripping. Within the pulp and paper sector, raw methanol is currently being extracted and purified commercially to produce a low-carbon fuel suitable for transportation purposes,[18] and has potential for use within the maritime sector.[19]

Conclusions

Several pulp and paper manufacturing by-products are currently being produced and marketed as low carbon fuels in the European market. Much of the material from EU's RED framework could readily be incorporated into US based models such as DOE's 45ZCF–GREET model, so that the GHG reduction benefits of forest products industry derived transportation fuels be recognized.

About NCASI

NCASI is a non-profit environmental research institute that seeks to create credible scientific information required to address the environmental information needs of the forest products industry in North

[17] USDA. November 06, 2024. United States Tall Oil Exports to the Nordics Surge. Report Number: FI2024-0002 lists a number of biorefinery and biofuel producers in Finland and Sweden.

[18] https://solutions.sulzer.com/post/sulzer-and-andritz-power-world-s-largest-biomethanol-plant-in-finland

[19] https://methanol.org/wp-content/uploads/2023/05/Marine_Methanol_Report_Methanol_Institute_May_2023.pdf

America. NCASI conducts surveys, provides advice regarding technically appropriate methods of conducting environmental field measurements, undertakes technical studies such as scientific literature reviews and research compilations, and sponsors scientific research by universities and others to document the environmental performance of industry facility operations and forest management, and to gain insight into opportunities for further improvement in meeting sustainability goals. The nature of our research provides us with a unique lens on the development of metrics related to documenting the performance of forest products industry operations, given our research into the development and field application of sampling and analytical test methods, along with nearly 80 years of experience in reviewing and treating data that characterize environmental releases from the sector.

References

ASTM D804-12(2022) Standard Terminology Relating to Pine Chemicals, Including Tall Oil and Related Products

Beca AMEC Limited. 2006. Report for NCASI - Turpentine Review.

Dogaris, I., Lindström, M.E., Henriksson, G. 2019. Critical parameter for tall oil separation I: the importance of the ratio of fatty acids to rosin acids. *Tappi Journal* 18(9):547-555.

Foran, C.D. 1992. Chapter 4. Tall Oil Soap Recovery in Chemical Recovery in the Alkaline Pulping Processes (G. Green and R.P. Hough, Eds.) Tappi Press, Peachtree Corners, GA, USA. Pp. 45-56.

Huibers, D.T.A. 2000. Tall Oil in Kirk-Othmer Encyclopedia of Chemical Technology 2001 John Wiley & Sons, Inc. DOI: 10.1002/0471238961

NCASI. 1995. Acetaldehyde, acetone, methanol and methyl ethyl ketone contents of kraft mill condensates. NCASI Technical Bulletin No. 702. NCASI Research Triangle Park NC.

Venkatesh, V., Lapp, W.L., Parr, J.L. 1997. Millwide methanol balances: Predicting and evaluating HAP emissions by utilizing process simulation techniques. *Tappi Journal* 80(2):171-176.

Zhu, J.Y., Yoon, S.-H., Liu, P.-H., Chai, X.-S. 2002. Methanol formation during alkaline wood pulping. *Tappi Journal* 83(7):13 pgs.