# Sustainable aviation fuels

## Raw materials

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Fastmarkets

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# The different SAF pathways mostly use different raw materials

Main product / co-product | By product / residual | Waste

## HEFA

- Used cooking oil (UCO)
- Tallow – animal fat
- Corn oil
- Used cooking oil (UCO)
- Soybeen, rapeseed, camelina, palm oil
- Brassica carinata (“Ethiopian mustard”)

## Gasification / FT

- Municipal solid waste
- Agricultural residues
- Forestry residues
- Short-rotation wood crops
- Herbaceous energy crops (e.g., switchgrass)

## Alcohol-to-Jet

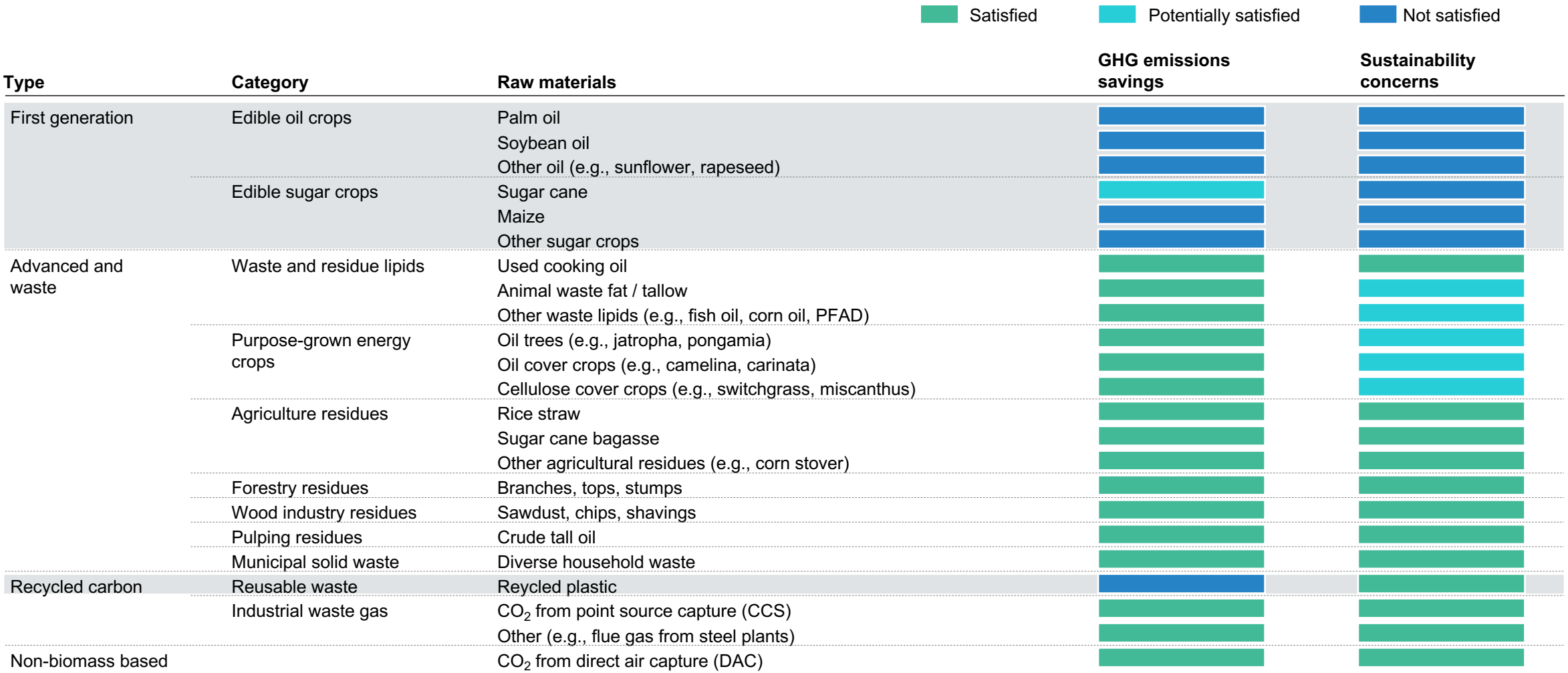
- Agricultural residues
- Forestry residues
- Sugarcane
- Corn grain
- Herbaceous energy crops (e.g., switchgrass)
- Molasses

## Power-to-Liquid

- $CO_2$

Source: Fastmarkets

# Sustainability criteria will influence what feedstocks are preferred




| Type | Category | Raw materials | GHG emissions savings | Sustainability concerns |
|---|---|---|---|---|
| First generation | Edible oil crops | Palm oil | Not satisfied | Not satisfied |
| | | Soybean oil | Not satisfied | Not satisfied |
| | | Other oil (e.g., sunflower, rapeseed) | Not satisfied | Not satisfied |
| | Edible sugar crops | Sugar cane | Potentially satisfied | Not satisfied |
| | | Maize | Not satisfied | Not satisfied |
| | | Other sugar crops | Not satisfied | Not satisfied |
| Advanced and waste | Waste and residue lipids | Used cooking oil | Satisfied | Satisfied |
| | | Animal waste fat / tallow | Satisfied | Potentially satisfied |
| | | Other waste lipids (e.g., fish oil, corn oil, PFAD) | Satisfied | Potentially satisfied |
| | Purpose-grown energy crops | Oil trees (e.g., jatropha, pongamia) | Satisfied | Potentially satisfied |
| | | Oil cover crops (e.g., camelina, carinata) | Satisfied | Potentially satisfied |
| | | Cellulose cover crops (e.g., switchgrass, miscanthus) | Satisfied | Potentially satisfied |
| | Agriculture residues | Rice straw | Satisfied | Satisfied |
| | | Sugar cane bagasse | Satisfied | Satisfied |
| | | Other agricultural residues (e.g., corn stover) | Satisfied | Satisfied |
| | Forestry residues | Branches, tops, stumps | Satisfied | Satisfied |
| | Wood industry residues | Sawdust, chips, shavings | Satisfied | Satisfied |
| | Pulping residues | Crude tall oil | Satisfied | Satisfied |
| | Municipal solid waste | Diverse household waste | Satisfied | Satisfied |
| Recycled carbon | Reusable waste | Reycled plastic | Not satisfied | Satisfied |
| | Industrial waste gas | $CO_2$ from point source capture (CCS) | Satisfied | Satisfied |
| | | Other (e.g., flue gas from steel plants) | Satisfied | Satisfied |
| Non-biomass based | | $CO_2$ from direct air capture (DAC) | Satisfied | Satisfied |

Source: World Economic Forum.

# The Roundtable on Sustainable Biomaterials (RSB) is the leading body providing sustainability certification for SAF

**Roundtable on Sustainable Biomaterials**

- Global, multi-stakeholder independent organization
- Members include businesses, NGOs, academics, governments and UN organizations
- Drives development of a bio-based and circular economy through certification and partnerships
- Main body certifying SAF for sustainability; SAF represented 17% of certified products in 2019
- Applies the CORSIA standard, recognized by the International Civil Aviation Organization (ICAO)

**Criteria: 12 principles for sustainable fuel production**

1. Legality
2. Planning, monitoring and continuous improvement
3. Greenhouse gas emissions (GHG)
   - Minimum of 50% GHG emission reduction compared to the fossil fuel baseline
4. Human and labor rights
5. Rural and social development
6. Local food security
7. Conservation
8. Soil
9. Water
10. Air quality
11. Use of technology, inputs and management of waste
12. Land rights

**Scope**

- Certification of SAF made from
  - **Primary biomass** (e.g., oil or sugar crops, energy grasses)
  - Biomass from **end-of-life products and residues** (e.g., UCO, agri and forestry residues, animal fats)
  - **Municipal solid waste**
- Covers **all CORSIA lifecycle steps**
  - Feedstock cultivation
  - Harvesting, collection, recovery
  - Processing and extraction
  - Transportation to processing and fuel production facilities
  - Feedstock-to-fuel conversion
  - Fuel transportation, distribution and combustion in aircraft

Source: Roundtable on Sustainable Biomaterials.

# UCO to be the most widely available source of ”sustainable” feedstock

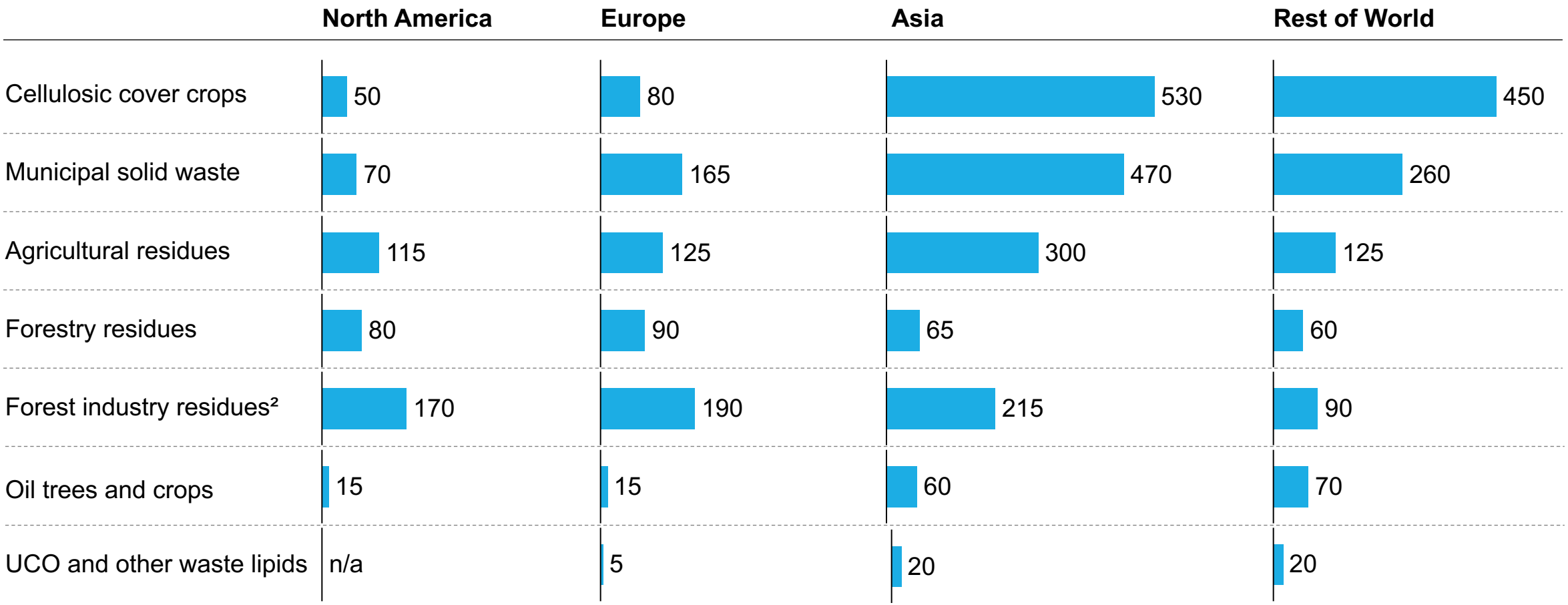
| Main SAF raw materials | Estimated percent share of production, 2025 | Sources | Key challenges |
|---|---|---|---|
| Used cooking oil (UCO) | 60 | Restaurant industry, households, food processing, recycling companies | Availability, cost, traceability and competition with road biodiesels |
| Palm fatty acid distillate (PFAD) | 15 | Crude palm oil producers mainly based in Southeast Asia | Oil palm plantations often cited as key driver of deforestation |
| Crop residues | 10 | Large-scale agricultural operations | Aggregation is costly and supply is seasonal; crop residuals have ecological benefit when left in the field |
| Municipal solid waste (MSW) | 5 | Household and commerical waste, particularly non-recyclable waste such as plastics | Aggregation and sorting for waste with high caloric value is costly |
| Forest residues | 5 | Forest harvesting and wood products manufacturing waste and residuals | Wide sourcing area and supply is currently dedicated to other secondary markets |
| Virgin vegetable oils | 5 | Global virgin oil (palm, peanut, olive, soybean) producers | Primary use is food industry; additional sustainability concerns related to land usage with some vegetable oils (palm, soya, etc.) |
| Other | <1 | Pulp producers (crude tall oil) and non-edible crops, such as carinita | Limited global availability of crude tall oil, establishing sufficient supply chains for other products is costly |

E.g., industrial gases, used tires, tallow.

Source: Fastmarkets.

# Long-term supply potential is highest for novel feedstocks, including forest and crop residues

**Total theoretical supply (estimates),** Million tonnes[1]

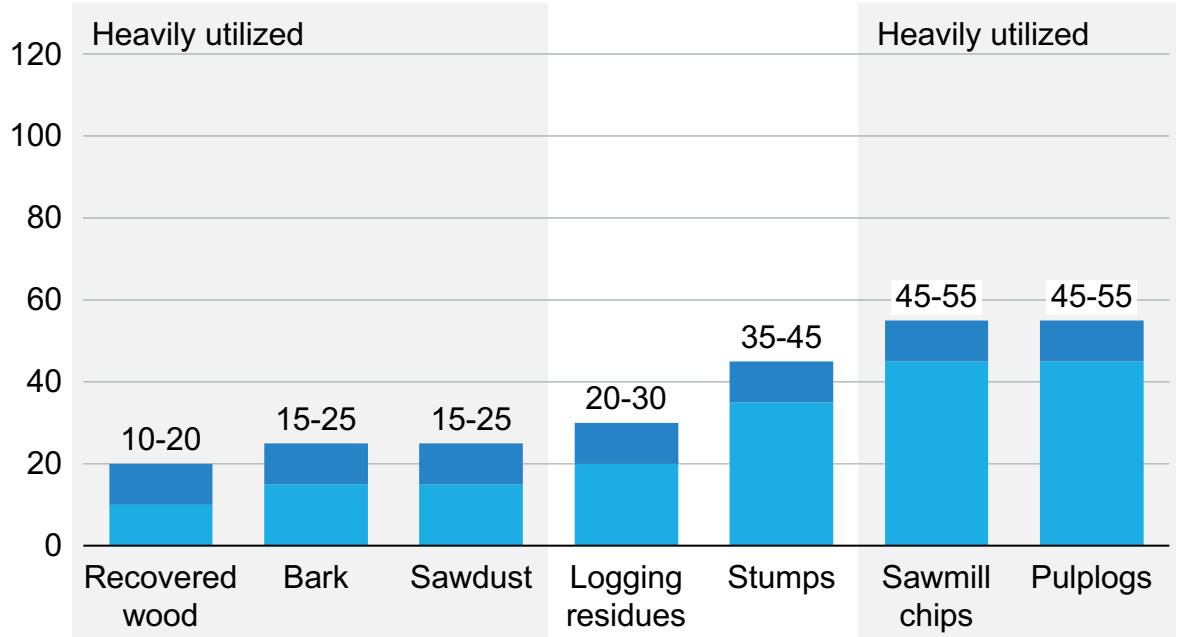



1. Dry biomass for lignocellulosic materials (forest and wood residues, agricultural residues, cover crops).
2. Most of these industry residues are already used in the wood and pulp industries; SAF would need to compete.

Source: Interviews; World Economic Forum; Fastmarkets analysis.

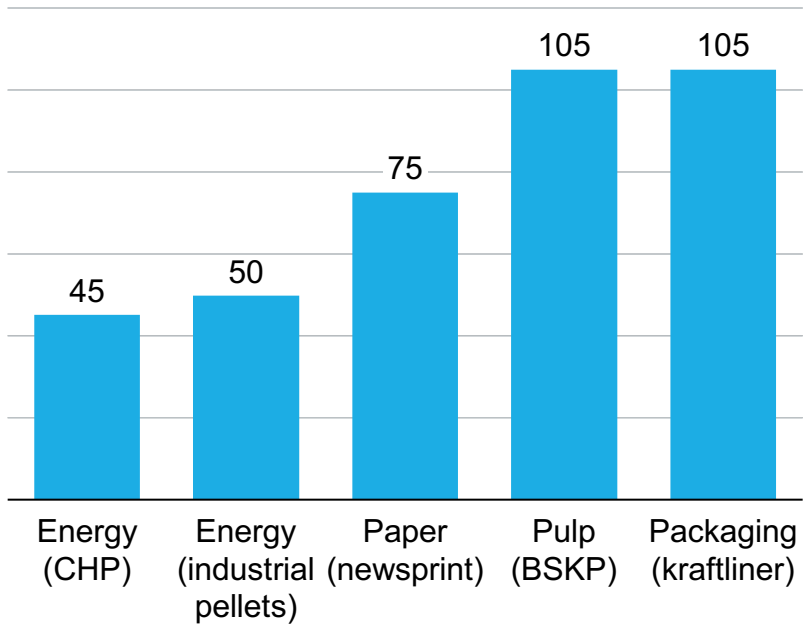
# Most forest biomass already utilized by forest industries, which have strong buying power

**Typical forest biomass costs, Europe**
EUR / $m^3$




| Current use | Recovered wood | Bark | Sawdust | Logging residues | Stumps | Sawmill chips | Pulplogs |
|---|---|---|---|---|---|---|---|
| Energy, pellets | ✓ | ✓ | ✓ | ✓ | | | |
| Panels | ✓ | | ✓ | | | | ✓ |
| Pulp & paper | | | | | | ✓ | ✓ |

**Buying power of existing forest industries (Sweden),** EUR / $m^3$ on cash cost basis




Source: O'Kelly Acumen.

# Forest industries generate around 600 million dry tonnes of wood residues, but these are mostly already utilized and highly-valued

## Types of forest industry residues

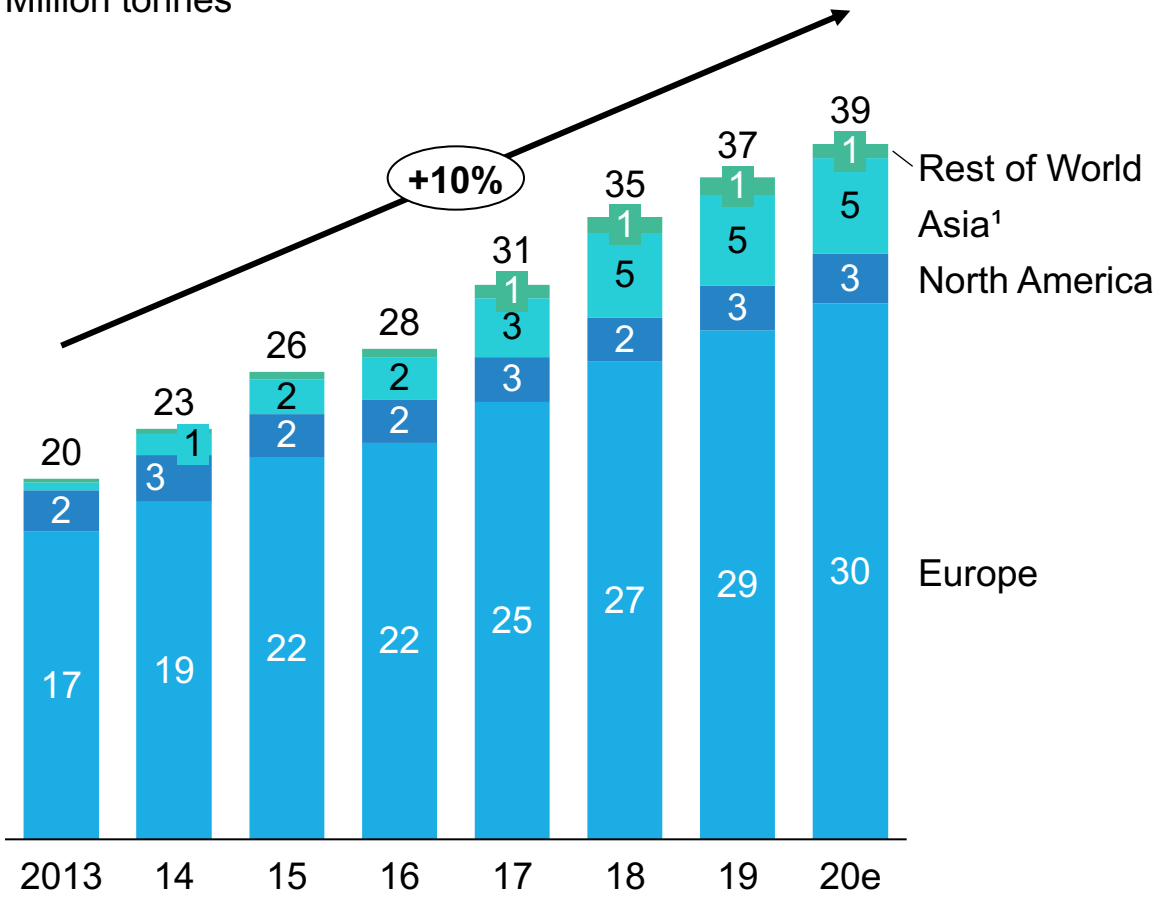
| | Description | Current use | Total supply potential[1] (estimate), Million dry tonnes |
|---|---|---|---|
| **Wood industry residues** | • Chips, sawdust and shavings are by-products at sawmills and plywood mills – clean wood highly valued as raw material for other products | • Pulp raw material (chips)<br>• Panels and pellets raw material (sawdust, shavings) | ~335 |
| **Pulping residues** | • By-products of chemical pulping process (kraft or sulfite)<br>• "Black/brown liquor" containing lignin, hemicellulose and sometimes tall oil<br>• Vital source of energy for pulp mills, used as integral part of pulping chemical recovery | • Pulp mill energy<br>• Biofuels and biochemicals | ~150 |
| **Bark** | • Tree bark after trees are debarked – either in forest or more often at industrial facilities (pulp mills, sawmills, panel mills) | • Sawmill and pulp mill energy<br>• Biofuel for energy (e.g., CHP plants) | ~95 |
| **Recycled wood** | • Solid waste wood at the end of its life, including industrial (construction, packaging) and post-consumer | • Raw material for wood panels<br>• Animal bedding<br>• Garden mulch | ~85 |
| **Total** | | | **~665** |

1. Including volumes currently used.

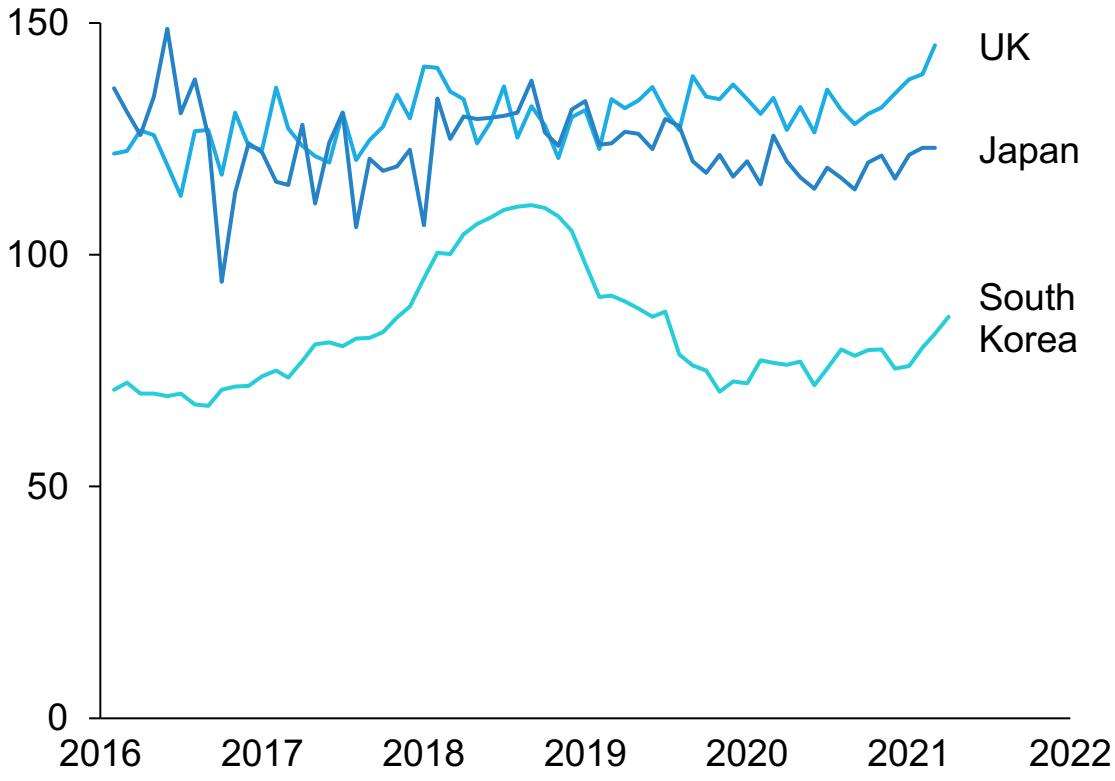
Source: Fastmarkets.

# Clean forest industry residues, such as sawdust, are in high demand as raw materials for growing energy pellet industry

**Global wood pellet demand**
Million tonnes



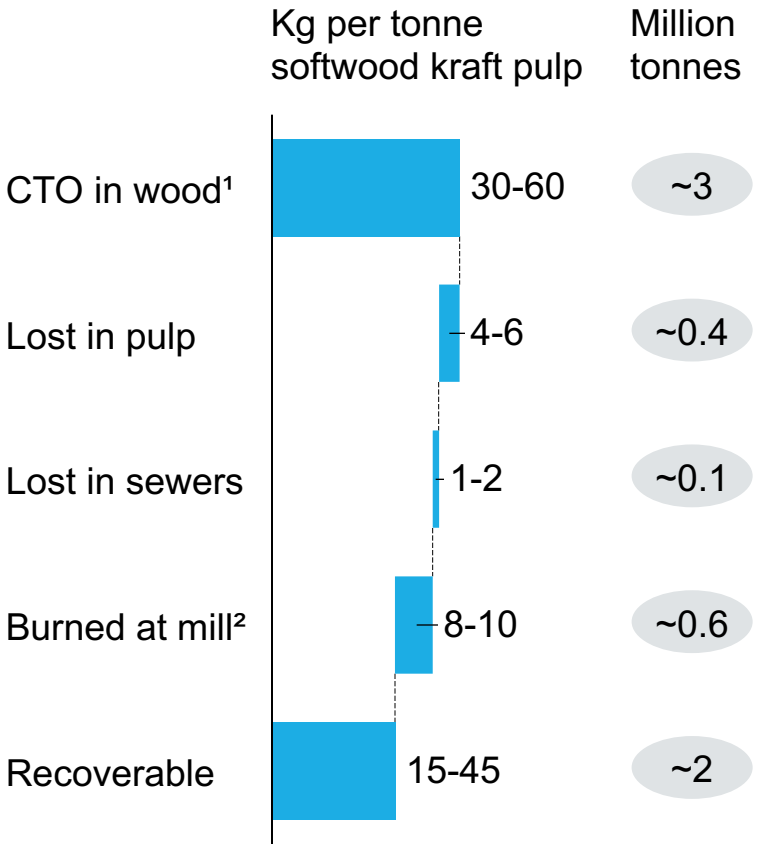

**Average import prices for wood pellets**
USD / tonne (nominal)




Source: Global Trade Atlas; European Pellet Council; FAOSTAT

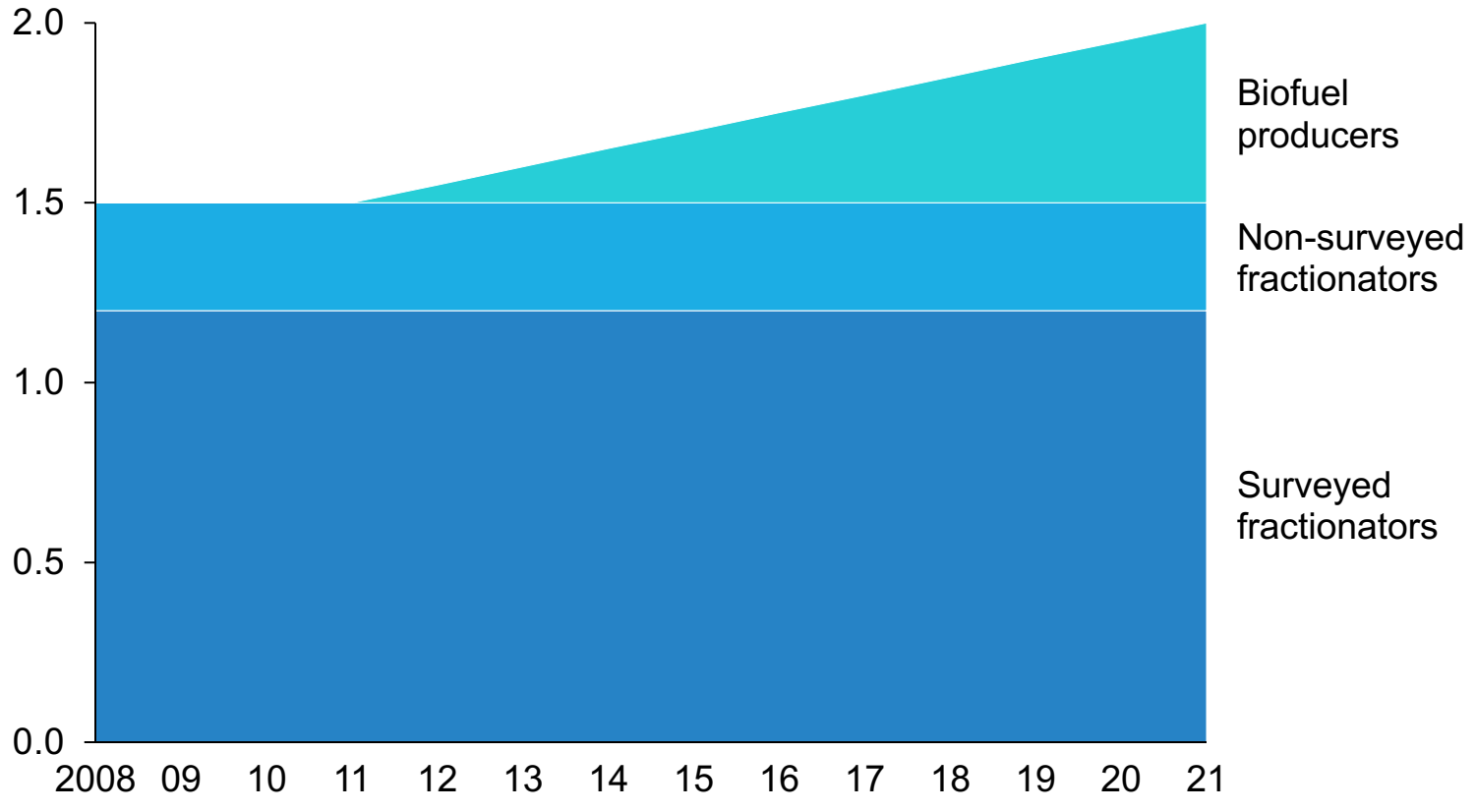
# Crude tall oil supply is limited by softwood kraft pulp production, and recoverable portion already used for biofuels and chemicals

**Estimated crude tall oil (CTO) supply, 2021**




**Global CTO demand growth**

Million tonnes




1. Varies by species and only found in softwood (coniferous) wood.
2. Burned in mill recovery boiler where pulping chemicals are processed, contributing to mill energy supply.

Source: Fastmarkets RISI.

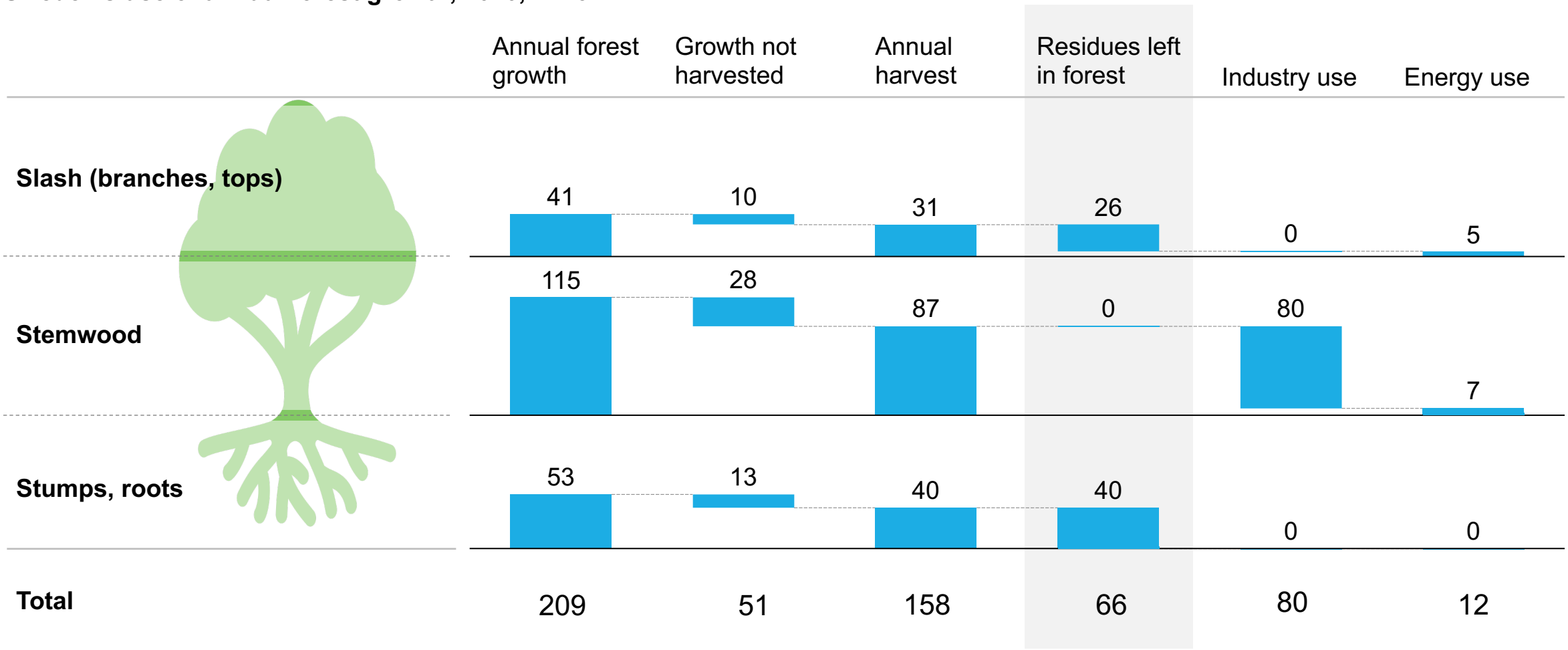
# There are three types of forest residues that arise during harvest

| Types of forest residues | Description | Typical volume<br>Cubic meter per cubic meter industrial roundwood harvest | Potential extraction<br>Percent |
|---|---|---|---|
| **Slash** | • Branches and tops of felled trees with diameter too small for commercial use<br>• High nutrient content restricts how much can be extracted, especially of smaller branches and foliage | 0.3 | 50 |
| **Stemwood waste** | • Offcuts and waste from main stem of tree, generated during log making, e.g., short sections between logs or defective stem wood (forked, split)<br>• Relatively large pieces, often concentrated around log-making sites (“landings”) | 0.1 | 100 |
| **Stumps and roots** | • Stumps of trees below felling height and portion of tree below ground level<br>• Extraction is costly and can involve significant disturbance | 0.4 | 10 |

Source: Fastmarkets; interviews.

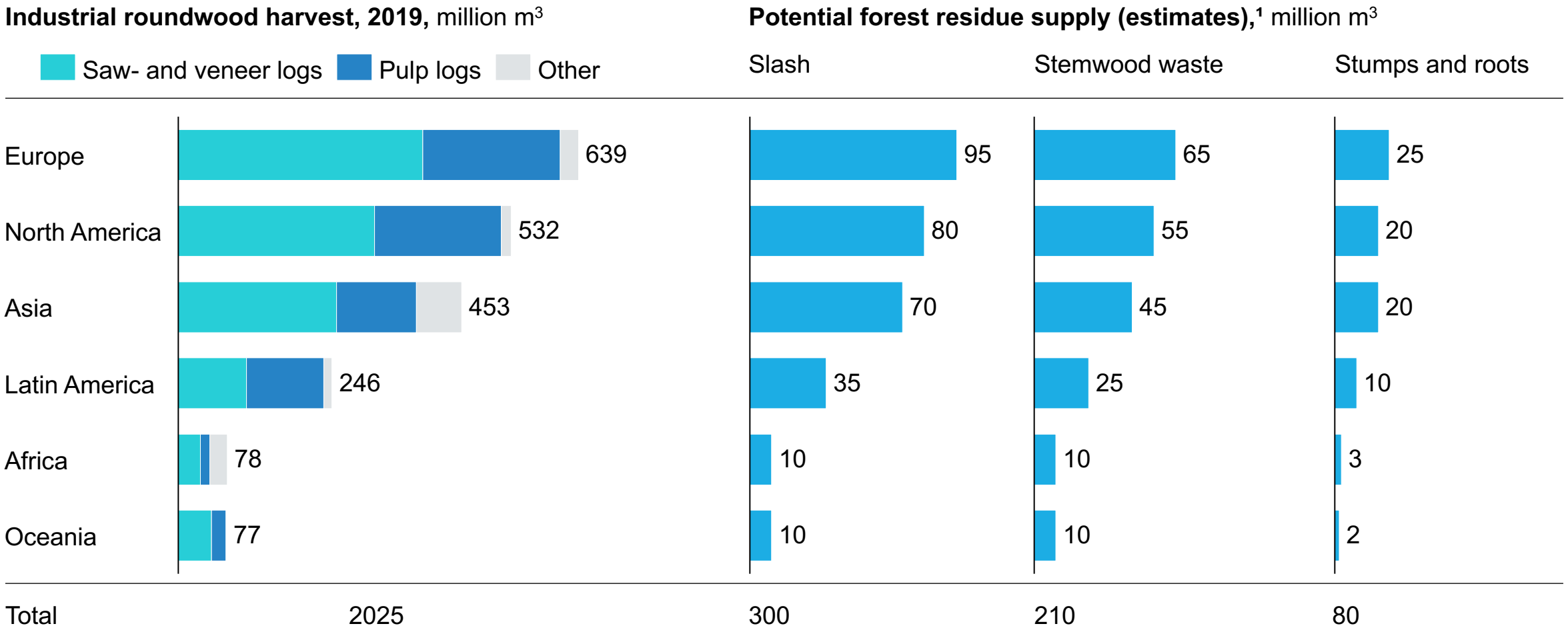
# Large volumes of forest residues from harvesting are currently unutilized (Sweden example)

**Sweden's use of annual forest growth, 2020,** million $m^3$




Source: Svebio (2020).

# Globally there are around 600 million m³ of forest residues that could be potentially extracted, most are not currently utilized

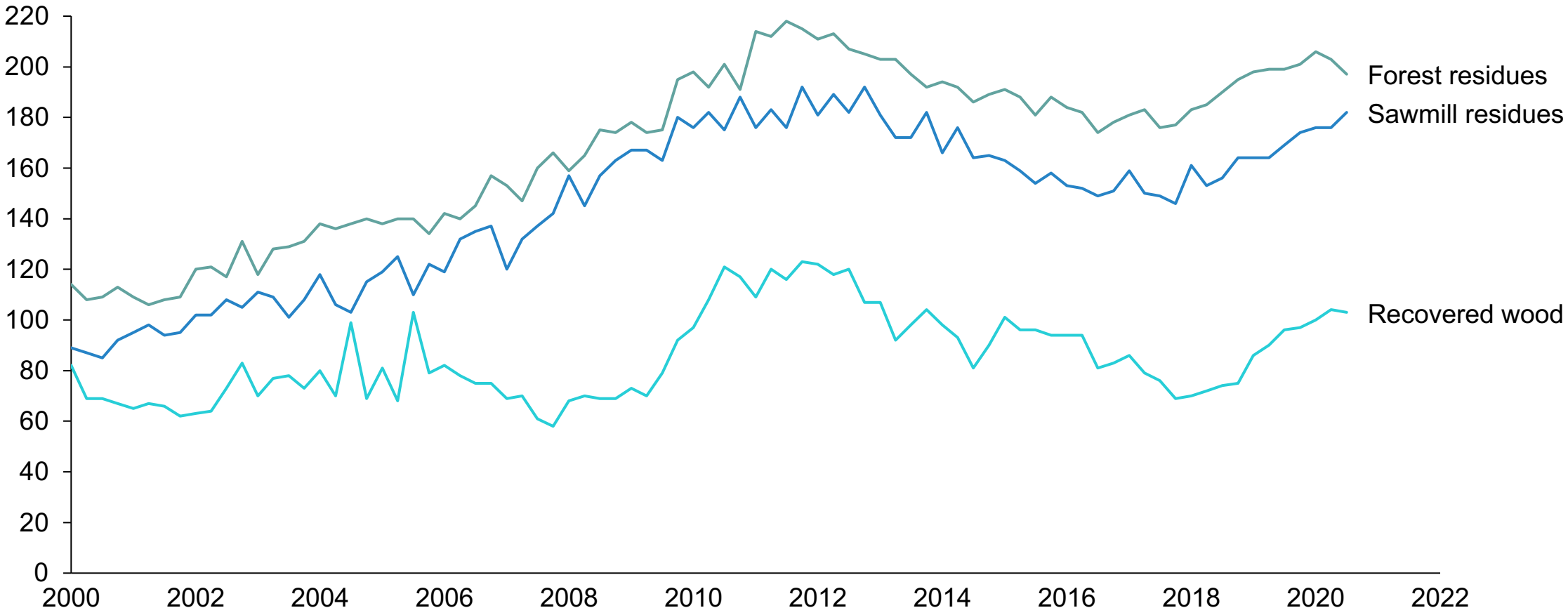



1. Assuming residue generation for slash, stemwood waste and stumps of 0.4, 01 and 0.1 m3 per m3 industrial roundwood harvest, respectively, and potential extraction rate of 50%, 100% and 10%, respectively.

Source: Fastmarkets.

# The price of forest-based feedstocks is flat even in regions with well-developed bioenergy sectors, e.g., Sweden

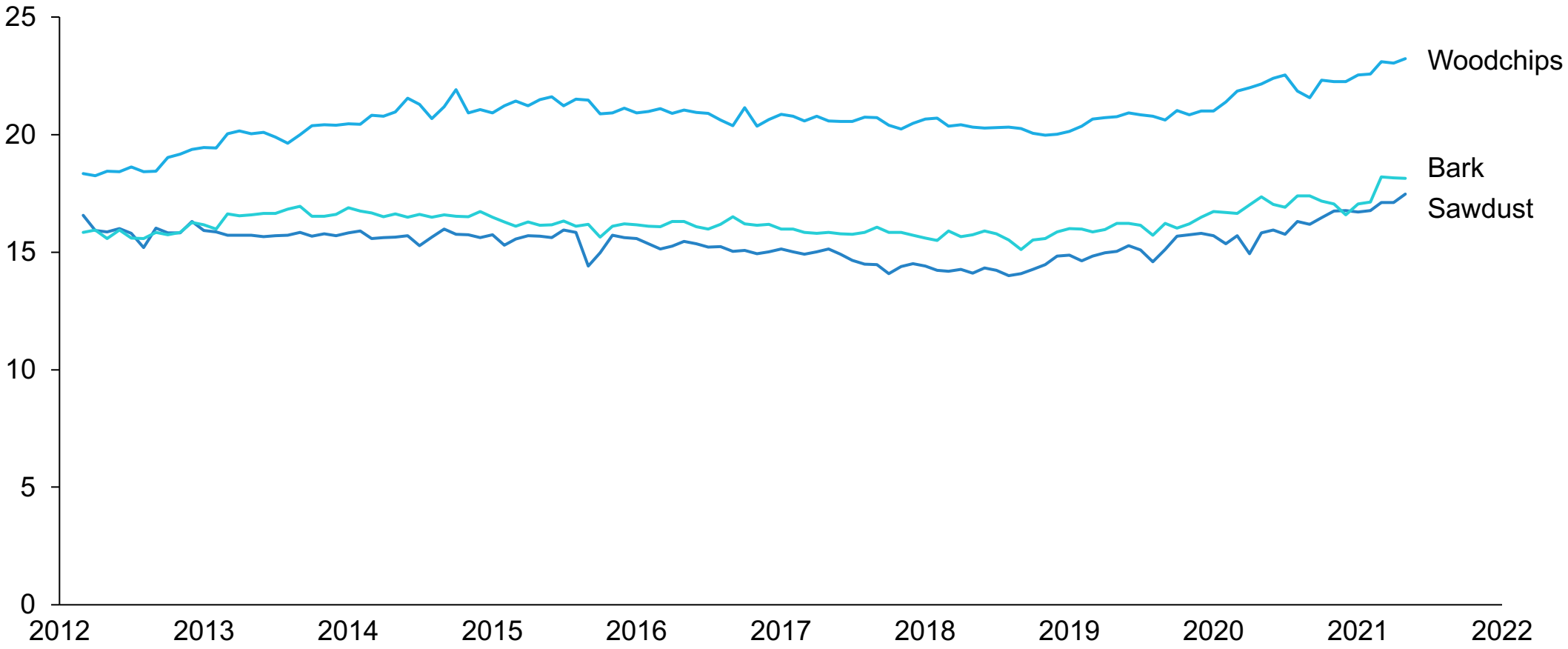
**Swedish prices for wood feedstocks to bioenergy;** SEK / MWh, delivered energy plant




Source: Swedish Energy Agency.

# The price of forest-based feedstocks is flat even in regions with well-developed bioenergy sectors, e.g., Finland

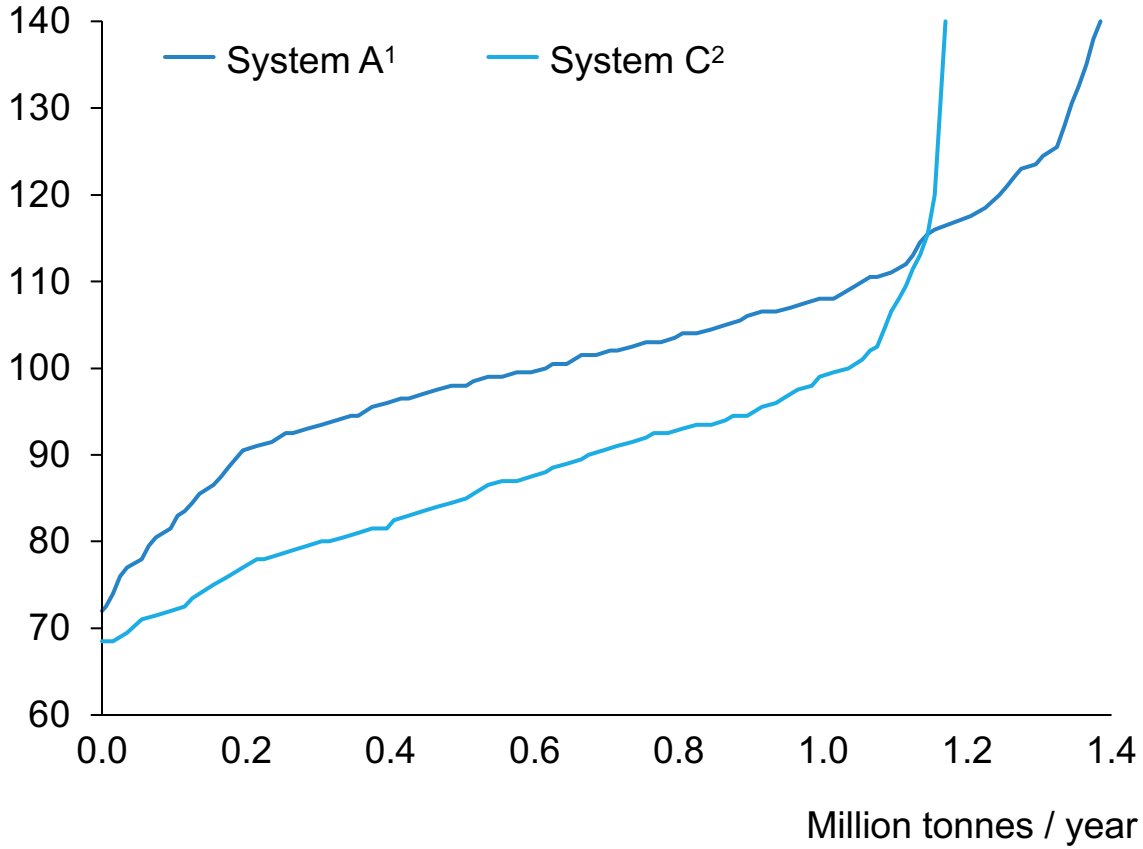
**Finnish prices for wood feedstocks to bioenergy;** EUR / MWh, delivered energy plant




Source: Fastmarkets RISI

# The cost curve for forest residues costs is steep; they need to be sourced locally, with focus on lower-cost fractions

**Biomass cost curve, potential site in northern Sweden**
EUR / dry tonne




1. Conventional harvest system with separate stemwood and residue extraction.
2. Alternative system including energy thinnings and excluding stump extraction.

Source: Joelsson et al. Integrated supply of stemwood and residual biomass to forest-based refineries, International Journal of Forest Engineering, 2016.

**Key take-aways**

- Forest residues are already used to some extent in Scandinavia, mainly in district heating plants.
- Currently, logging residues are normally extracted after stemwood (logs) has been extracted.
- Residues fractions includes tops, stemwood offcuts, branches and stump cores.
- Residues are sourced locally to reduce transport costs, usually less than 100 km by road.
- The cost curve for forest residues at a particular site is steep – costs increase rapidly, with marginal volumes, due to more expensive extraction and transport.
- More integrated forest harvesting systems (collection and sorting technologies) are being advanced to lower costs and develop a more efficient supply chain.

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Special report

fmrkts.com/saf2025

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