NewWave

MODIFIED WOOD PRODUCTS: What's the way forward?

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NewWave webinar series

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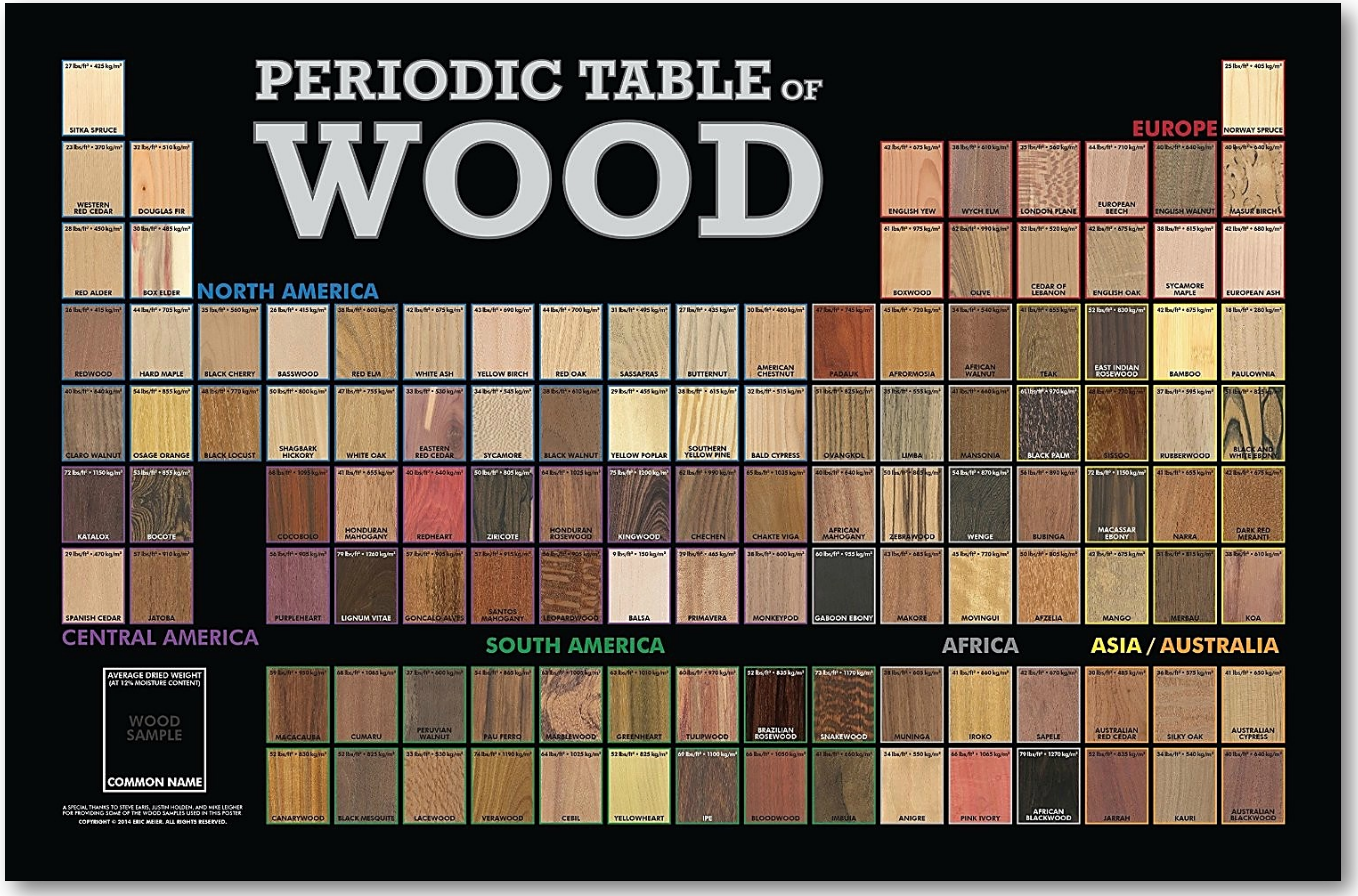
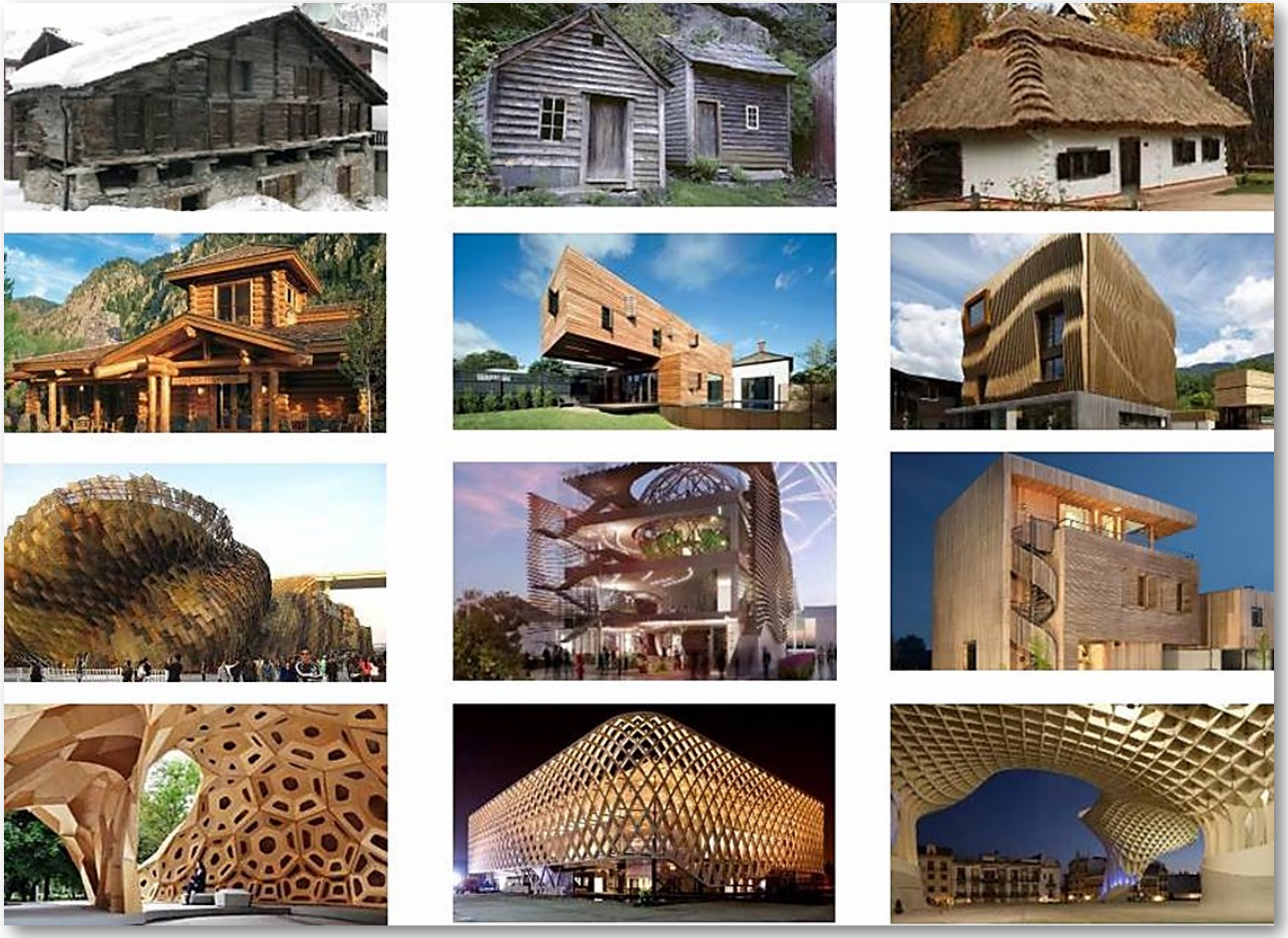
Diversity of wood

There are over **60 000** different **wood species**, that might be used for several applications.





Degradation processes during service life

type	weathering	decay	waterlogging	insects	vandalism	fire	flood	earthquake
causes								
Processes (chemical & physical)	oxidation hydrolysis erosion abrasion fracture	oxidation hydrolysis depolymerization reduction	oxidation hydrolysis swelling shrinkage	depolymerization chewing	abrasion cracking fracture	dehydration oxidation hydrolysis	swelling shrinkage freezing cracking	fracture cracking
affected properties	colour gloss roughness integrity	colour gloss density integrity mechanical properties	colour gloss density integrity mechanical properties	colour density integrity mechanical properties	colour integrity	colour density integrity mechanical properties	colour density integrity mechanical properties	integrity mechanical properties
aesthetic	✓	✓	✓	✓	✓	✓	✓	✓
function		✓	✓	✓		✓	✓	✓
safety		✓	✓	✓		✓		✓

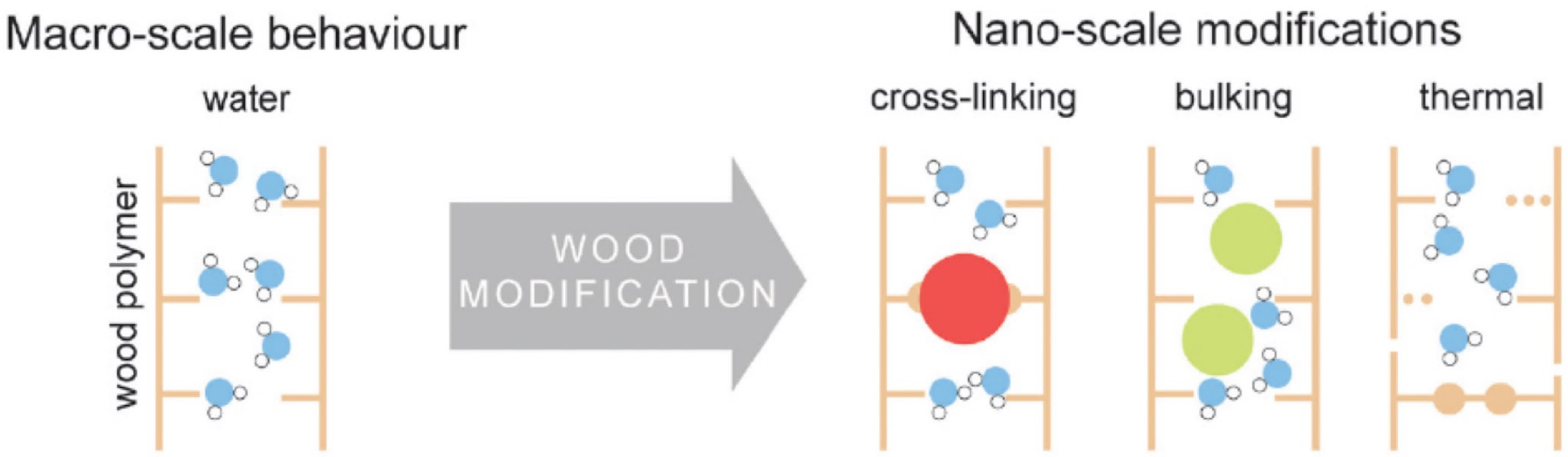
Wood modification processes

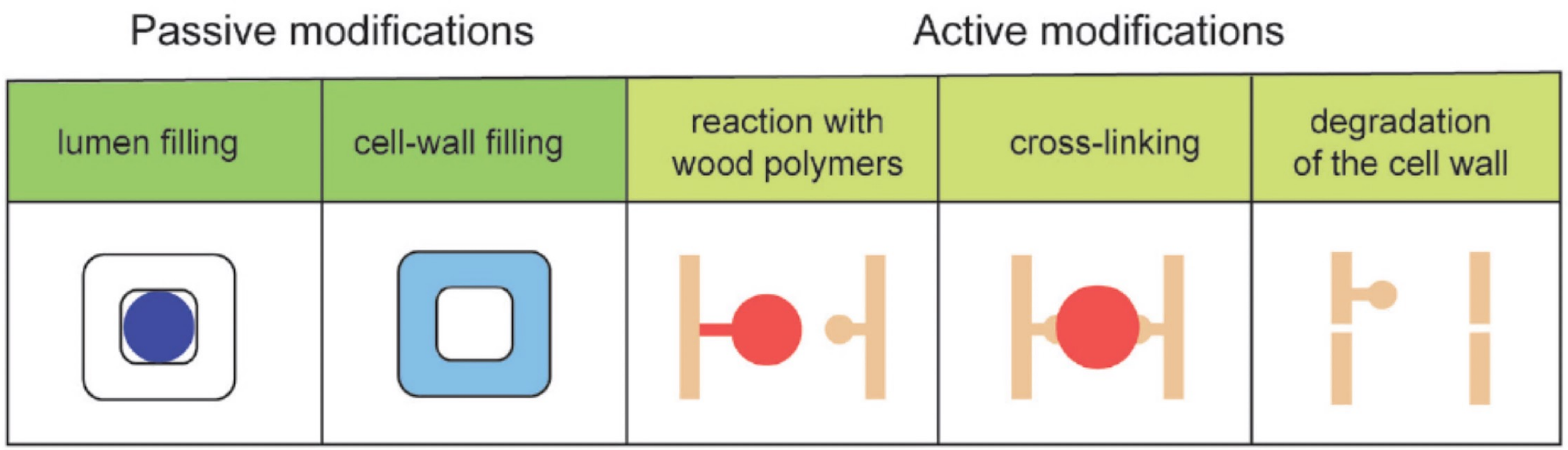
Active Modifications

- Result in a change to the chemical nature of the material

Passive Modifications

- Change the properties of the material, but without an alteration of the chemistry of the material





Jones D. and Sandberg D. DOI: 10.37947/ipbe.2020.vol1.1

Wood modification processes

Wood modification

Chemical processes

Active modification
- Acetylation (Accoya™)
- Resin impregnation
  - Compreg™
  - PF-resin
  - Other type of chemicals
- Furfurylation
  - Kebony™
  - Other types, e.g Keywood™ Nobelwood™
- DMDHEU
  - Belmadur™, HartHolz™
- Silicate/silane-based

Passive modification
- Resin impregnation (Impreg™)
  - Melamine resin
  - Other chemicals e.g. methacrylate
- Chitosan
- Natural oils/waxes/paraffins
- Polyethylene glycol
- Indurite™, Lignia™

Thermally-based processes

Thermo treatment
- Charring of wood surfaces

Thermo-hydro treatment
- Releasing internal stresses
- Softening
- Drying
- Ageing
- Thermal modification

Thermo-mechanical treatment
- Self-bonding of veneer
- Frictional wood welding

Thermo-hydro-mechanical treatment
- Bending
  - solid wood
  - laminated wood
- Moulding
  - surface
  - cross-sectional
- Bulk densification
- Surface densification

EPL processes*

Electromagnetic treatment
- Ultraviolet light (UV)
- Infrared light (IR)
- Microwave (MW)
- High-frequency (HF)

Plasma treatment
- Cold plasma
- Thermal plasma

Laser treatment
- CO_2 laser
- Excimer laser

* The use of electromagnetic radiation, plasma and laser for wood modification

Other processes

Biological treatment
- Degradation metabolites
- Fungal incising
- Enzyme treatment
- Bacterial incising
- Natural extracts
- Fungi antagonists

Biomimetics
- Water repellency
- Self cleaning

Mineralisation
- Silica-based
- Carbonate based

Novel media
- Supercricitcal fluids
- Ionic liquids

New methods
- Graft polymerisation
- Click chemistry
- Rhodium catalysis of hydroxyls
- Modification of chitosan

Overview of wood modification processes (modified from Jones et al., 2019).

Production capacity on the market

Thermal modification (ThermoWood, Firmolin...)
Acetylation (Accoya, Tricoya)
Furfurylation (Kebony, Nobelwood)
Silicate and silanes (Sioox)
Phenols (Lignia)
Oils, waxes and paraffin's

Processes ready for industrial implementation

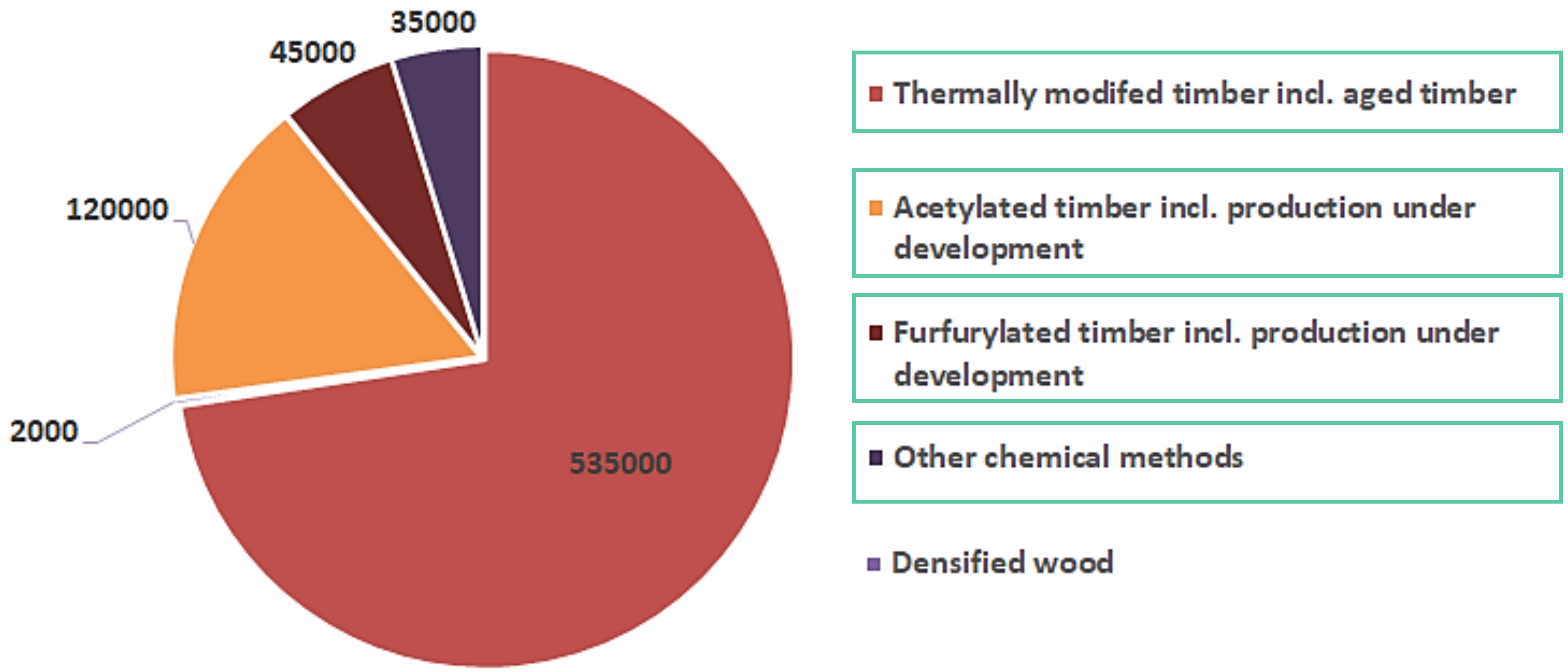
Melamine resin
DMDHEU (Belmadur)

Processes under development in research

Chitosan, lignins, tannins
Extractives etc.
Other chemicals

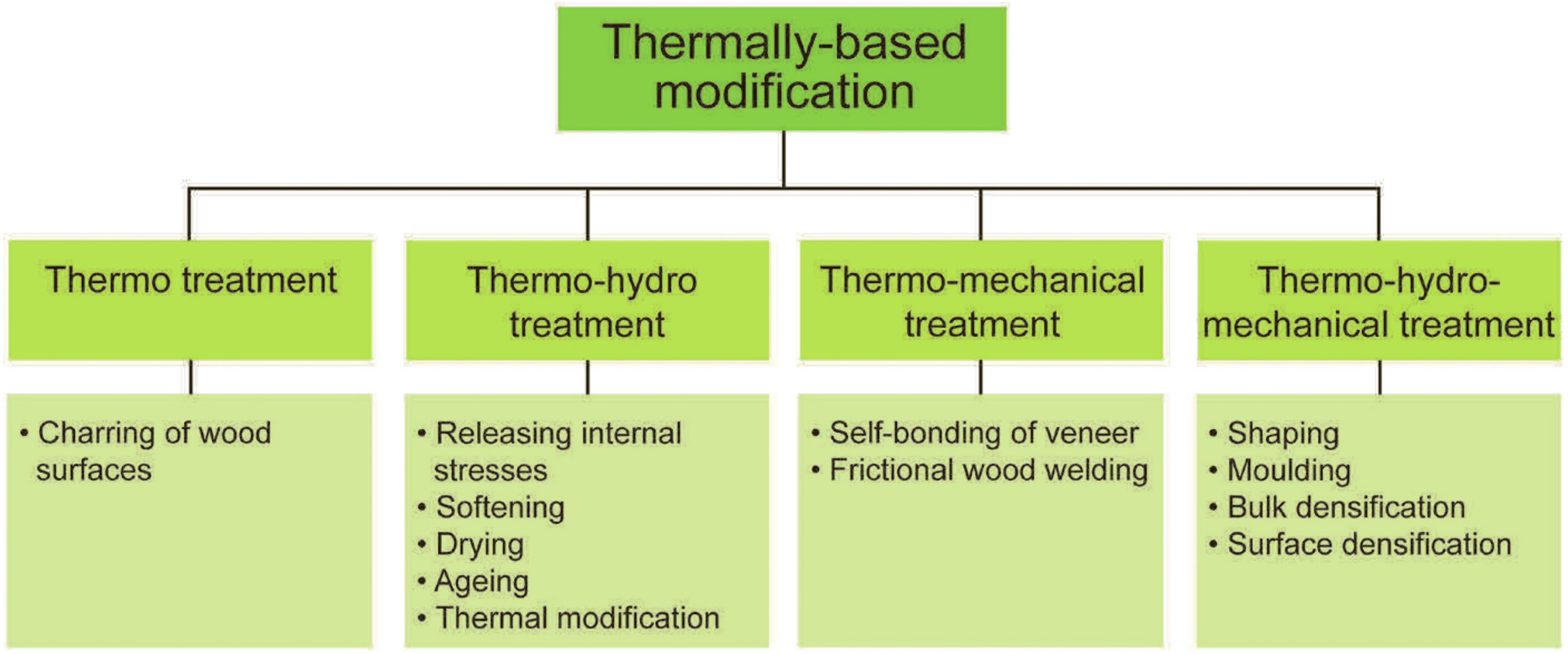
Wood modification in Europe

Europe currently holds nearly **70% share** in the **global wood modification market** value



Estimated annual production volumes for the nearest coming years
for some specific types of modified wood (in m^3)

Thermal modification



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Thermal modification

- Is commercialized procedure for **improving some characteristics of wood**

- The **changes** in the wood during thermal modification **are well understood**, involving softening and the redistribution of lignin components, the loss of acid groups and cross-linking and repolymerization that occur to varying degrees depending on the wood species.

- The **process conditions** play a significant role in the chemistry which takes place, hydrolysis and catalysis occurring more in closed system processes.

Definition

- According to the **European Committee for Standardization** (2008), thermally modified timber is wood in which the composition of the cell-wall material and its physical properties have been modified by exposure to a **temperature higher than 160 °C** with **limited access to oxygen**.
- There are various processes to achieve this, mostly differing in the way they exclude air/oxygen from the system. A **steam or nitrogen atmosphere** can be used, or the wood can be immersed in **hot oil**.
- There are a **variety of thermal modification methods** that can be applied to wood, and the exact method of treatment can have a significant effect upon the properties of the thermally modified wood. Important process variables includes:

Appearance

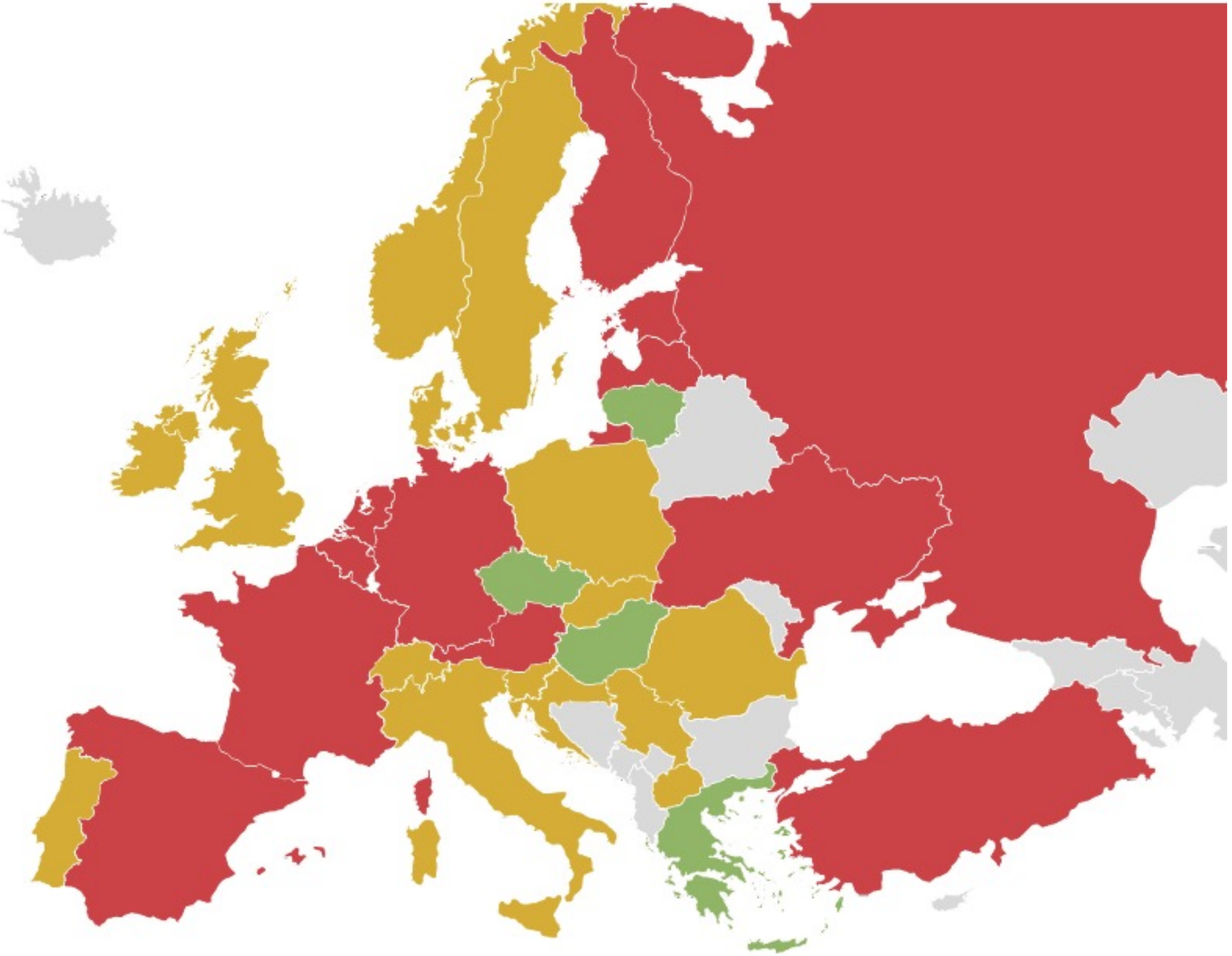

spruce
(Picea albies)
fir
(Abies alba)
larch
(Larix sp.)
beech
(Fagus silvatica)
oak
(Quercus sp.)
ash
(Fraxinus excelsior)
cherry
(Prunus sp.)
black locust
(Robinia p. acacia)
non-treated
160ºC
180ºC
200ºC
220ºC

Properties of thermally modified wood

- ✓ Brown colour creates product opportunities for indoor use
- ✓ Dimensional stability eases installation and improves coating adhesion
- ✓ Improved insulation can be useful for building applications, windows etc.
- ✓ Biological durability makes it possible to utilise wood species with limited natural durability (locally available species)
- ✓ Not suitable for ground contact/sea water/termites*
- ✓ Reduction in some strength properties calls for attention in dimensioning regarding e.g., joist distances in decking
- ✓ Machining requires more attention to detail than for unmodified woods

*without additional treatment

Production of TMW in Europe



Over 10 000 m^3/year

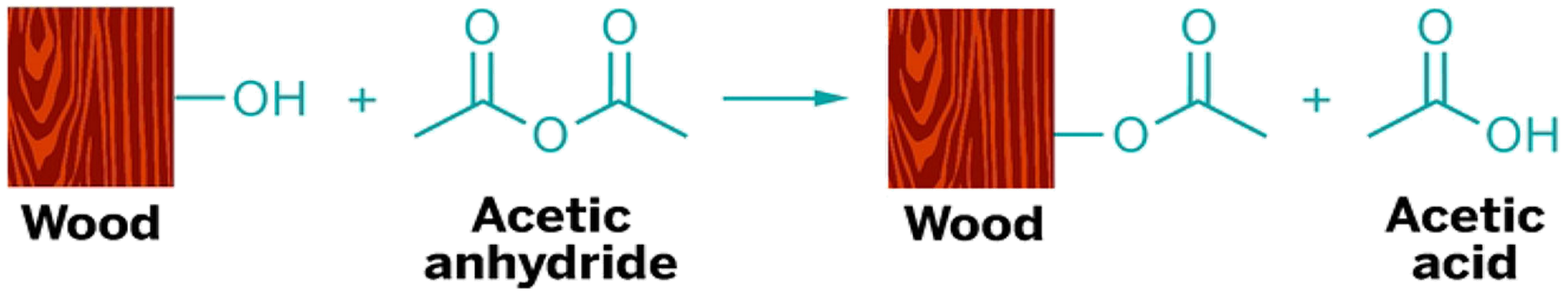
Under 10 000 m^3/year

No reported production volumes

No data available

Jones D. and Sandberg D. DOI: 10.37947/ipbe.2020.vol1.1

Aacetylation



Courtesy of dr. O. Gordobil

Appearance

alder

beech

radiata pine

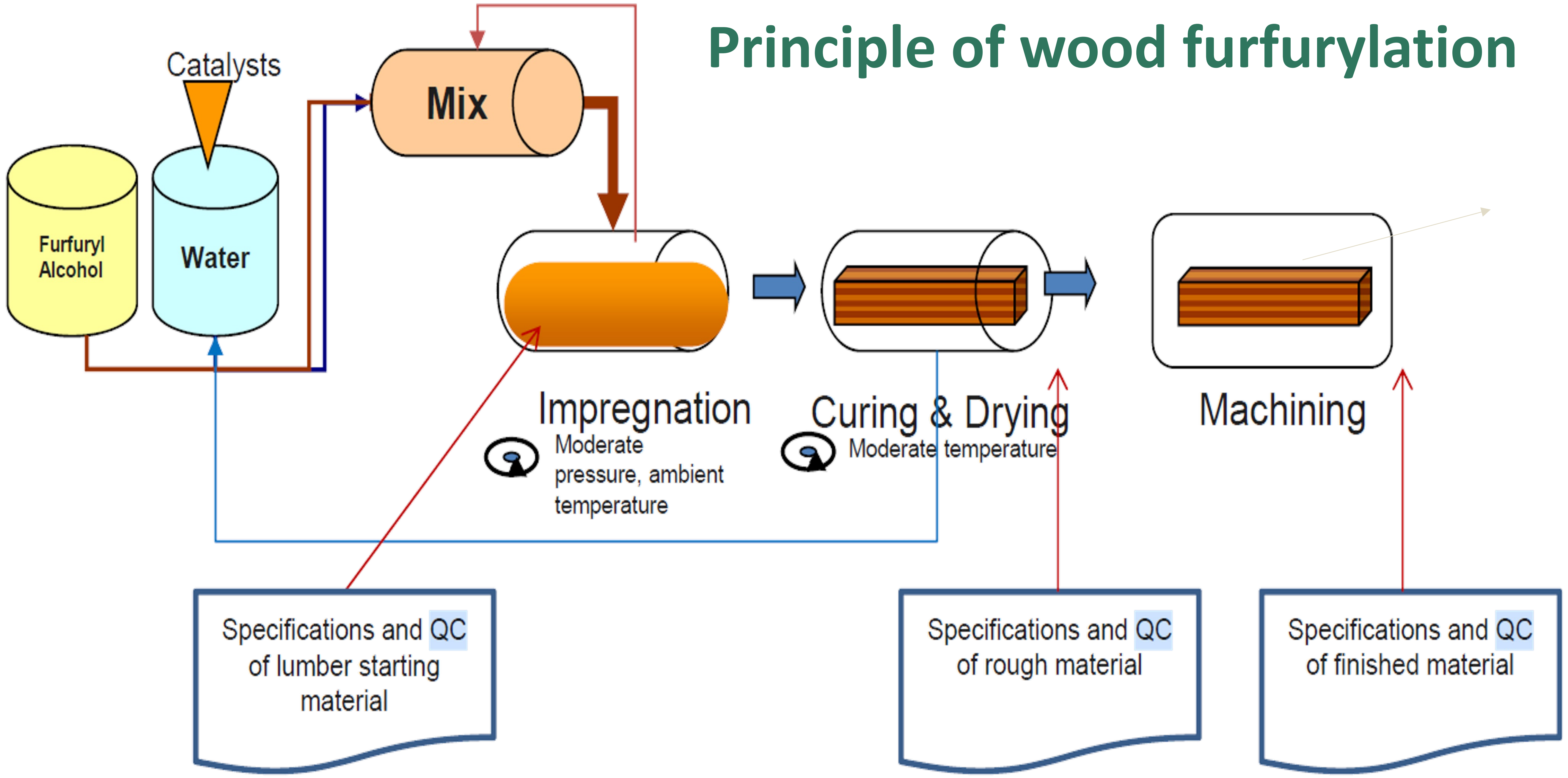
Properties of acetylated wood

- ✓ Reduce the moisture uptake (hydrophobic wood)
- ✓ Swelling and shrinkage behavior in changing humidity is reduced (70-75%)
- ✓ More dimensional stable
- ✓ Improved biological durability (similar to *Class 1*)
- ✓ High resistance to fungal attacks
- ✓ Resistant to subterranean and Formosan termites
- ✓ Excellent resistance to marine borer attacks
- ✓ Higher density
- ✓ Acetylated wood can become 15-30% harder than untreated wood
- ✓ No impacts on the mechanical (strength) properties

Furfurylation

- **Furfuryl alcohol** (FA) is a liquid produced from agricultural residuals/wastes.
- **Furfurylation** is the **impregnation** of wood with FA and catalyst.
- Heating the impregnated wood causes polymerization of the product into the long chains (solid furan polymer).
- The FA reacts with itself but possibly also with lignin. These polymers are grafted in the cell walls.
- It is mainly deposited in the wood cavities and the cell walls.
- It is very stable (no degraded or leaching out of the wood).

Principle of wood furfurylation



Courtesy of dr. R. Herrera Díaz

Appearance

furfurylated Radiata pine

furfurylated Scots pine

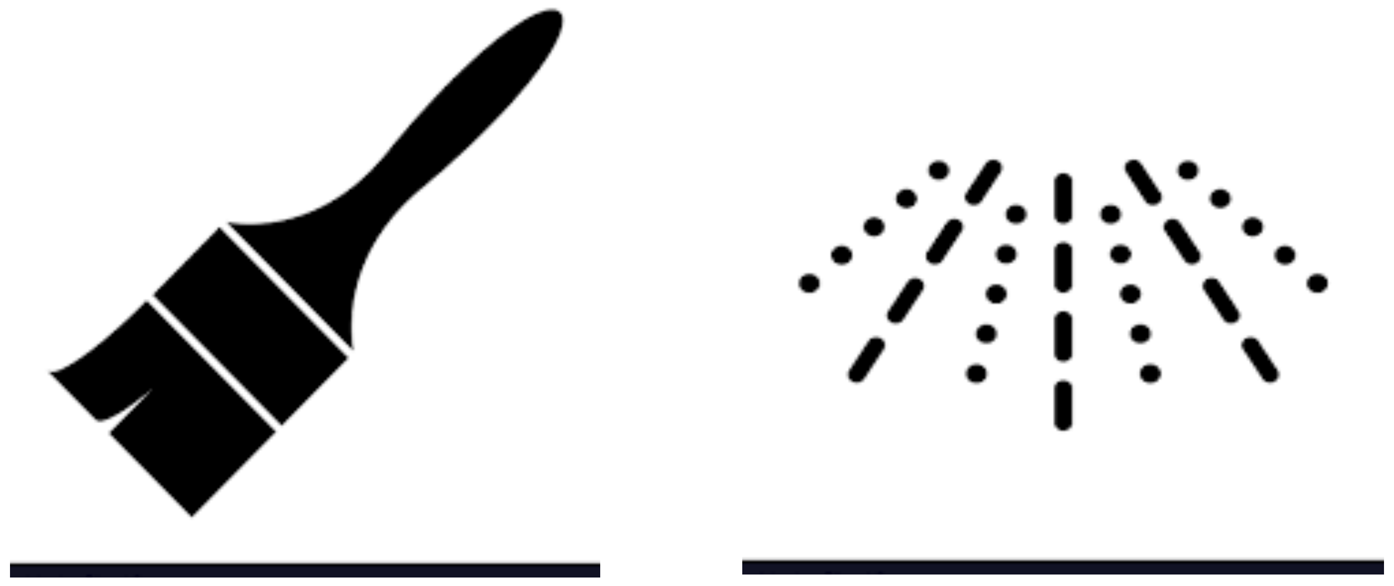
Properties of furfurylated wood

- ✓ Reduce the moisture uptake (hydrophobic wood)
- ✓ Swelling and shrinkage behavior in changing humidity is reduced (50%)
- ✓ More dimensional stable (>35%) then the untreated wood
- ✓ Improved biological durability (similar to *Class 1*)
- ✓ High resistance to fungal attacks
- ✓ Resistant to termites
- ✓ Uniform weathering
- ✓ Higher density
- ✓ Improved mechanical (stiffness, hardness) properties
- ✓ Slightly acidic - acid proof connectors such as stainless steel are recommended

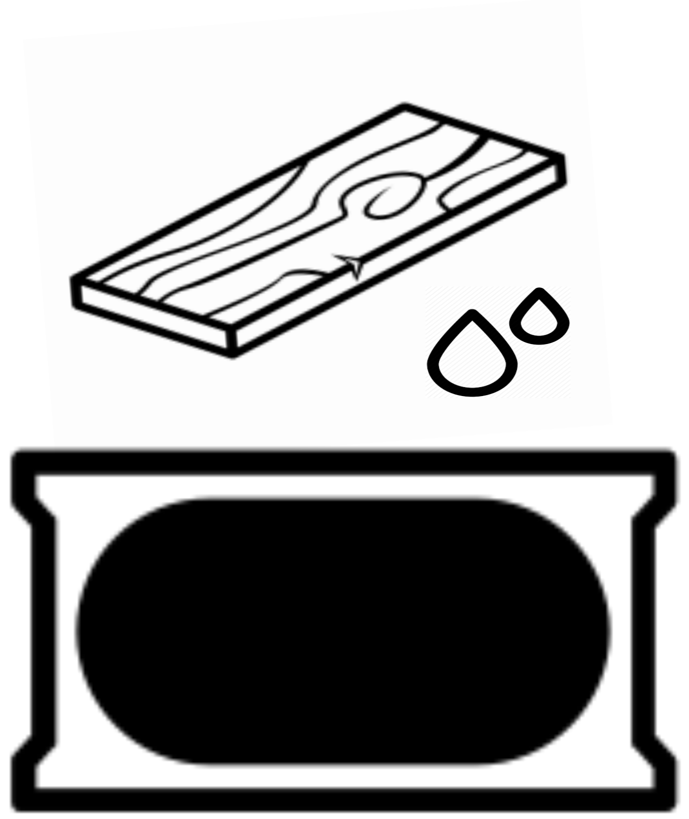
Impregnation treatments

The treatment process can be achieved **using chemicals and/or specific equipment**. Each method having its own strength and weaknesses. They can be divided in the in three main methods:

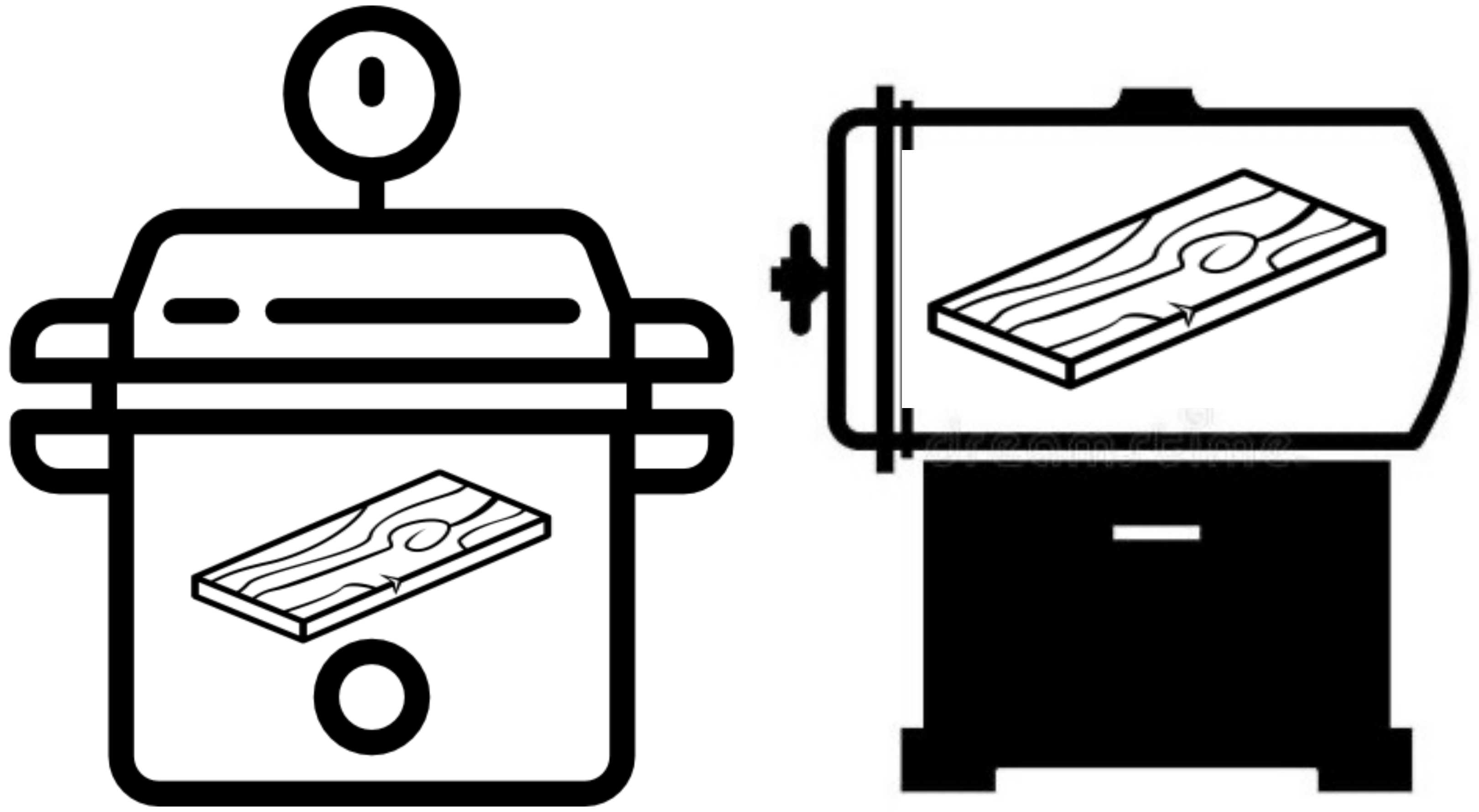
Non-pressure Impregnation	Diffusion treatments	Pressure Impregnation



Paints and sprays



Dipping processes



vacuum - overpressure – vacuum routines

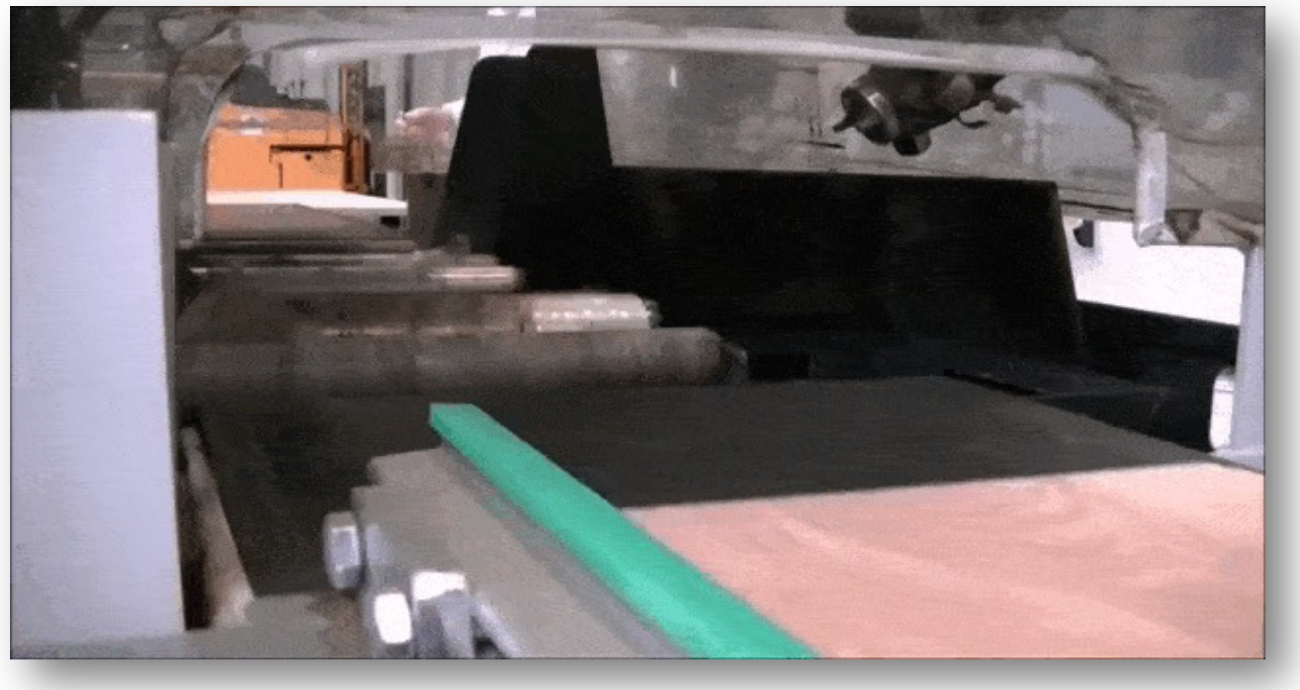
Courtesy of dr. R. Herrera Díaz

Non-pressure impregnation

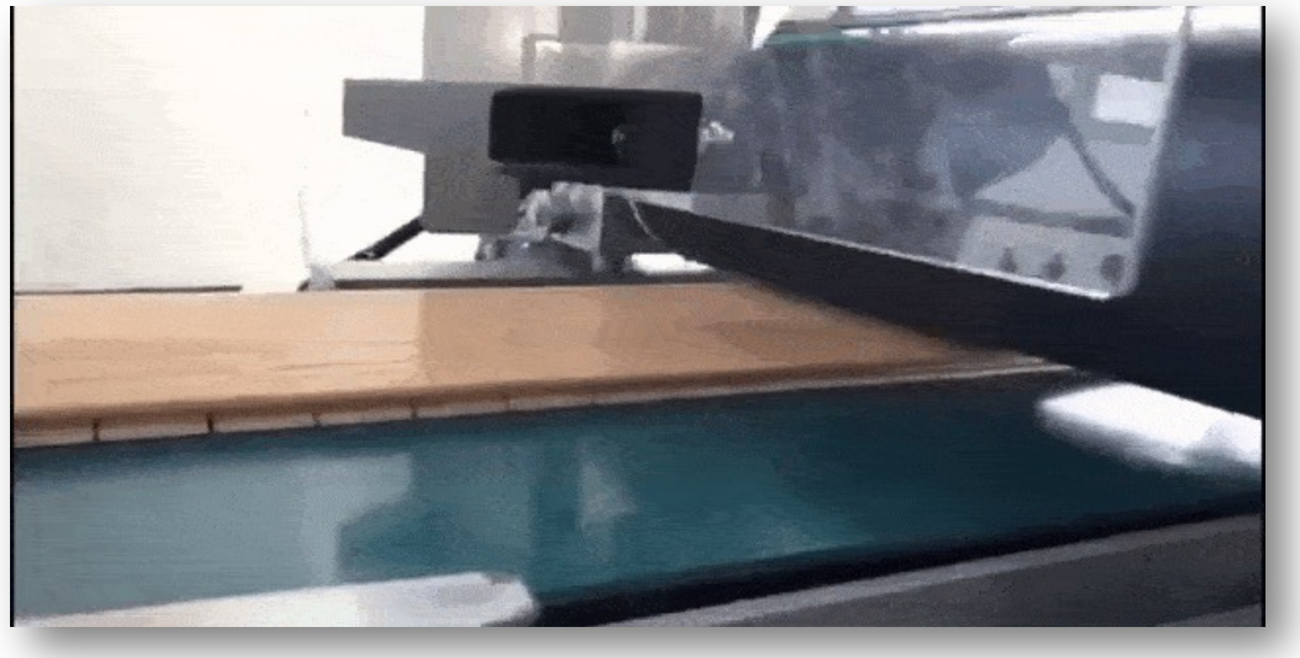
The wood surface plays a major role in how the preservative is absorbed. Unplanned absorbs twice as much preservative per unit area as planed timber.

Non-pressure Impregnation

- Brushing and spraying are simple and low-cost treatment methods but the depth of penetration and retention are very limited.
- Penetration across the grain is minimal and some penetration along the grain is possible.
- At the industrial scale wood coatings and finishing treatments are quite specific adding to formulations active compounds that react in the presence of UV light, heat, etc.



Industrial spraying system



Industrial coating line

Courtesy of dr. R. Herrera Díaz

Diffusion treatments

Are performed in suitable waterproof baths. Wood elements are arranged in packs which are submerged below the surface of the preservative by hydraulic arms. The treatments ensure that the entire wood surface is impregnated in a uniform manner.

Diffusion treatments

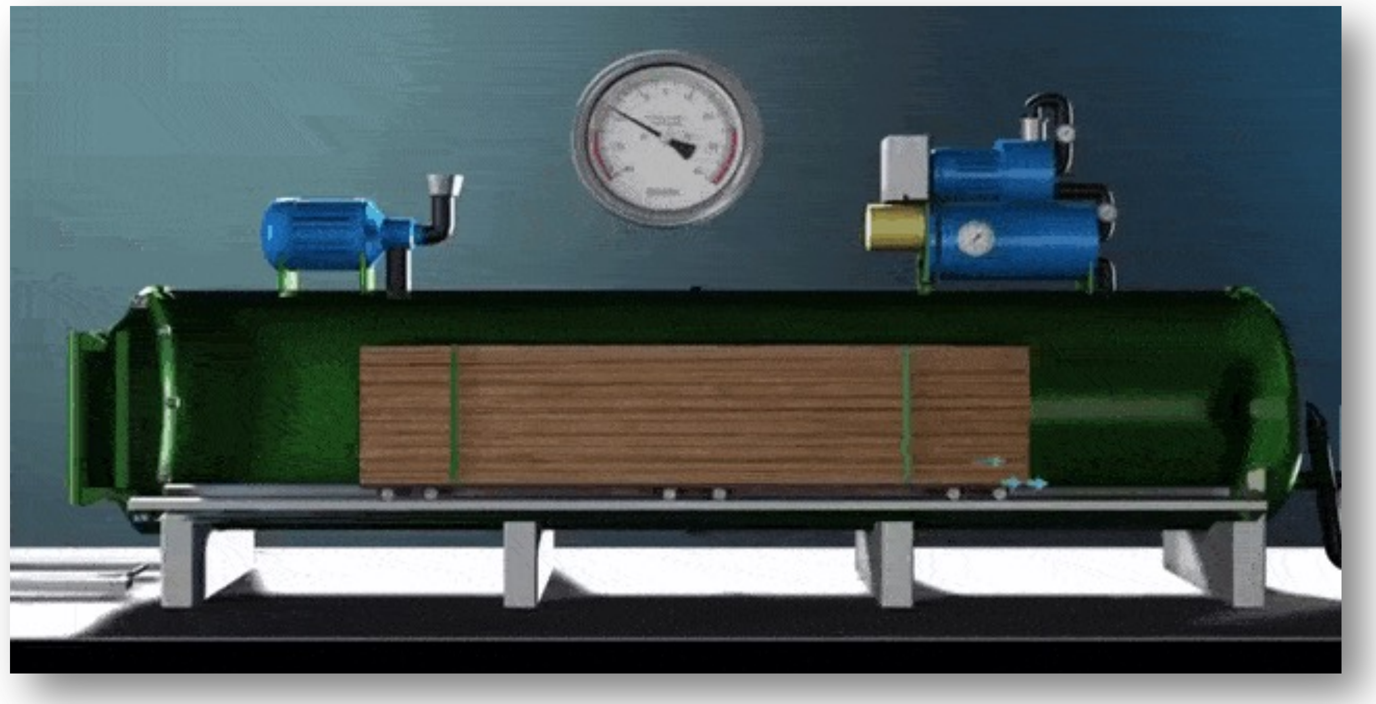
- Dipping for a seconds can increase end-grain penetration compared to brushing or spraying.
- Automatic immersion time is usually a few seconds and depends on how the line speed is configured.
- Typically for water-borne preservative (boron salts, fluorine compounds).
- The substances flow during diffusion is ensured by concentration gradient across the material.

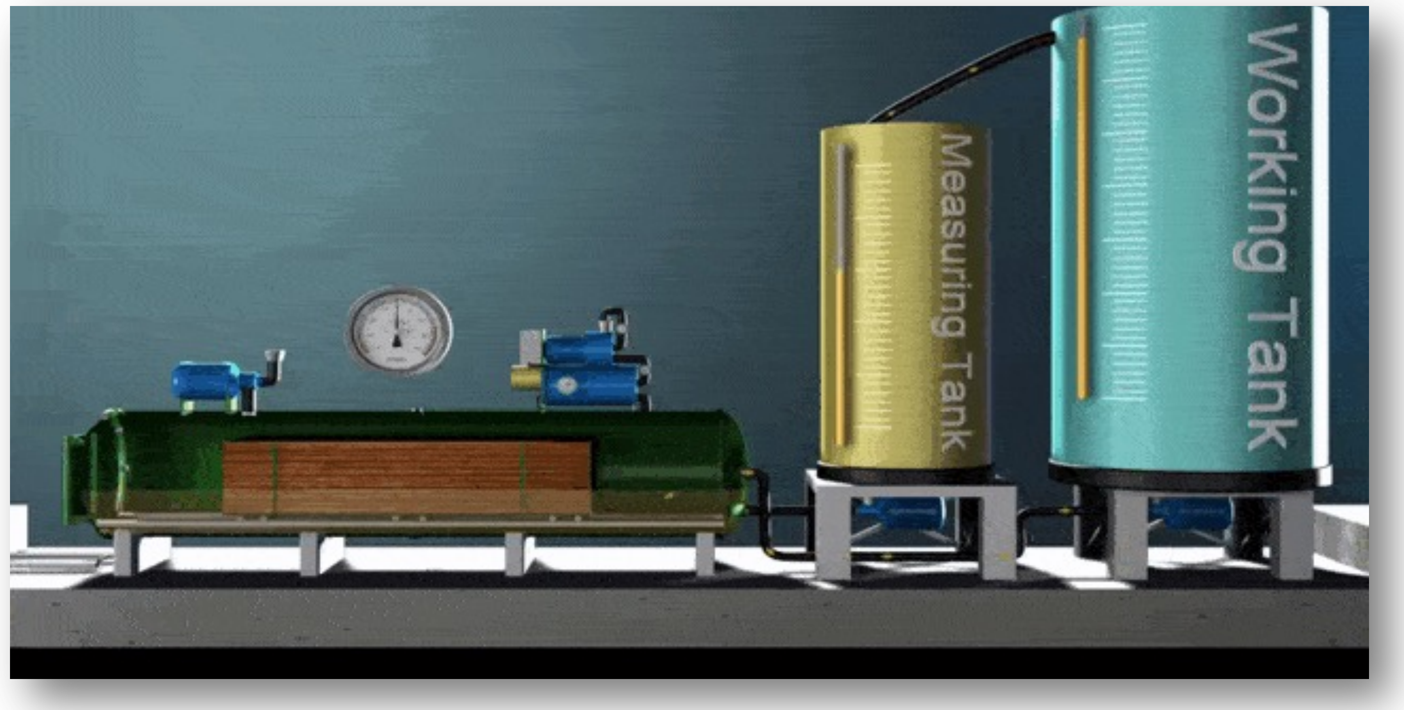
This method is mainly used for impermeable species

Courtesy of dr. R. Herrera Díaz

Pressure impregnation

Combinations of pressure and/or vacuum are used to force preservative into the wood and remove excess preservative at the end of the treatment.





Pressure impregnation

- Impregnation which combine vacuum and pressure is the most common and effective method.
- Times and magnitude of the pressure/vacuum cycles can vary greatly from treating plant to plant.
- There are many variations of treatment cycles, e.g. Bethell process, Vacuum process, Rueping process, Double Rueping process, Lowry process.

Courtesy of dr. R. Herrera Díaz

Appearance

vacuum impregnation with water + soaking of wet wood in concentrated AATMOS

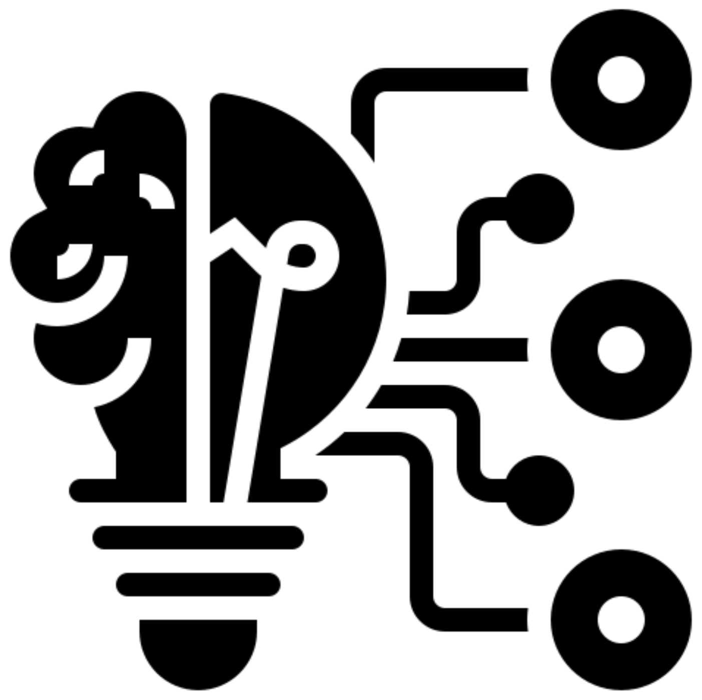
melamine treated wood

silicone and silicate based treated wood

Conference overview

- 170 participants from 30 countries
- 9 sessions
- 50 presentations and nearly same number of poste
- Chemical and thermal modification
- Densification & mineralization
- Industrial session (certification, quality control)
- Analysis
- New trends

Current trends



- Quality control of established processes
- Treatment of alternative wood species
- Hybrid modifications
- Green processes (in terms of chemicals, energy savings)
- Alterative processes (biobased, enzymatic, biomimetic)
- New functionalities (phase changing materials, transparent wood, etc)

WP6: ML4 Manufacturing line for wood modification

Funded by the European Union

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Project overview

PERIOD: 01.04.2022 – 31.03.2026

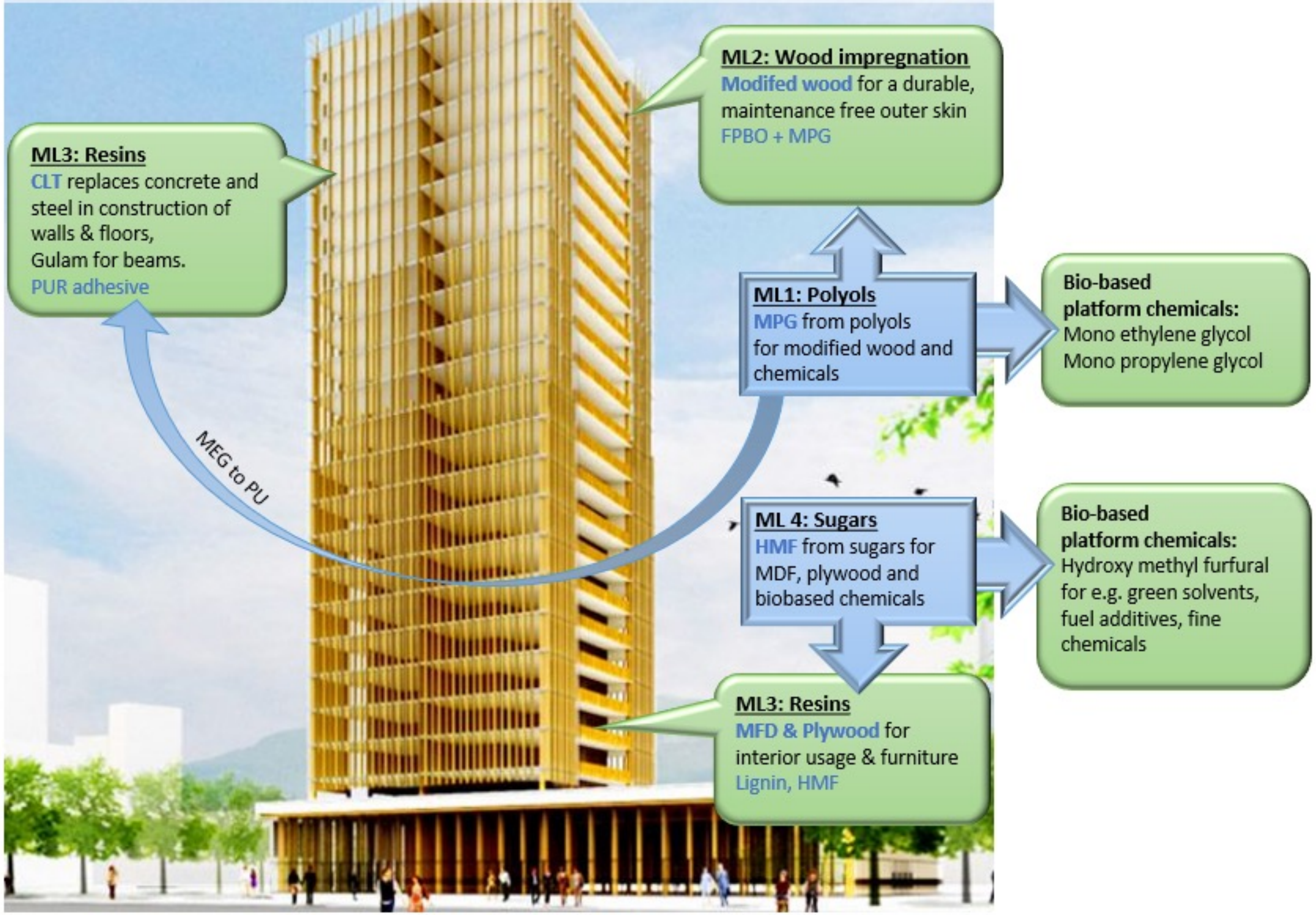
BUDGET: €5,057,580.00

FINANCING: HORIZON EUROPE-RIA

COORDINATOR: B.T.G. Biomass technology group BV (the Netherlands)

11 PARTNERS FROM 6 COUNTRIES (Netherlands, Belgium, Italy, Spain, Slovenia, Switzerland)

NewWave: building a circular economy



residual biomass & end-of-life products

fast pyrolysis bio-oil from thermo-chemical fractionation

furan-based chemicals

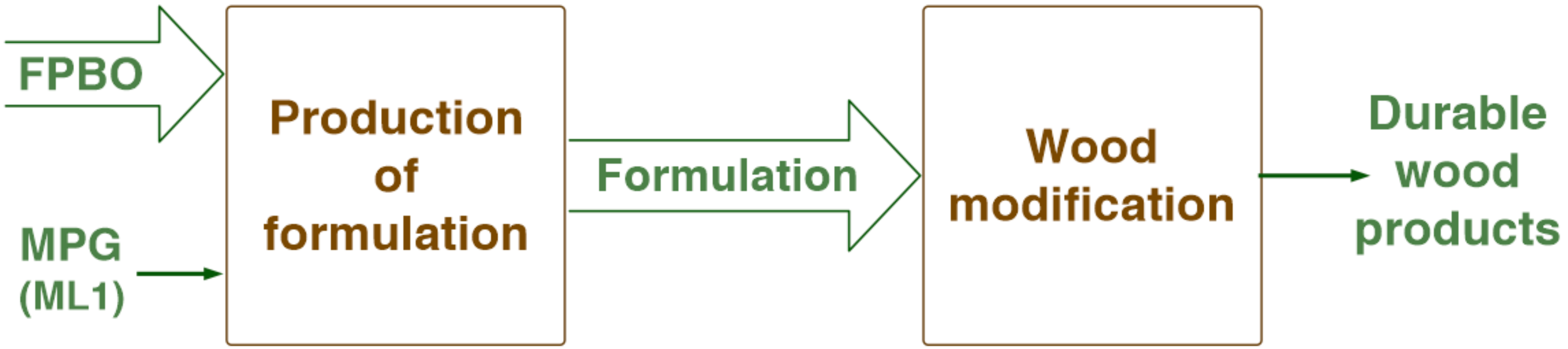
polyols & polyurethanes

engineered wood products

modified wood

Work package 6

ML4 - Manufacturing line for modified wood



WP6 overview

Involved partners: INNO, BTG, FCO

Timeline: start M3, end M48

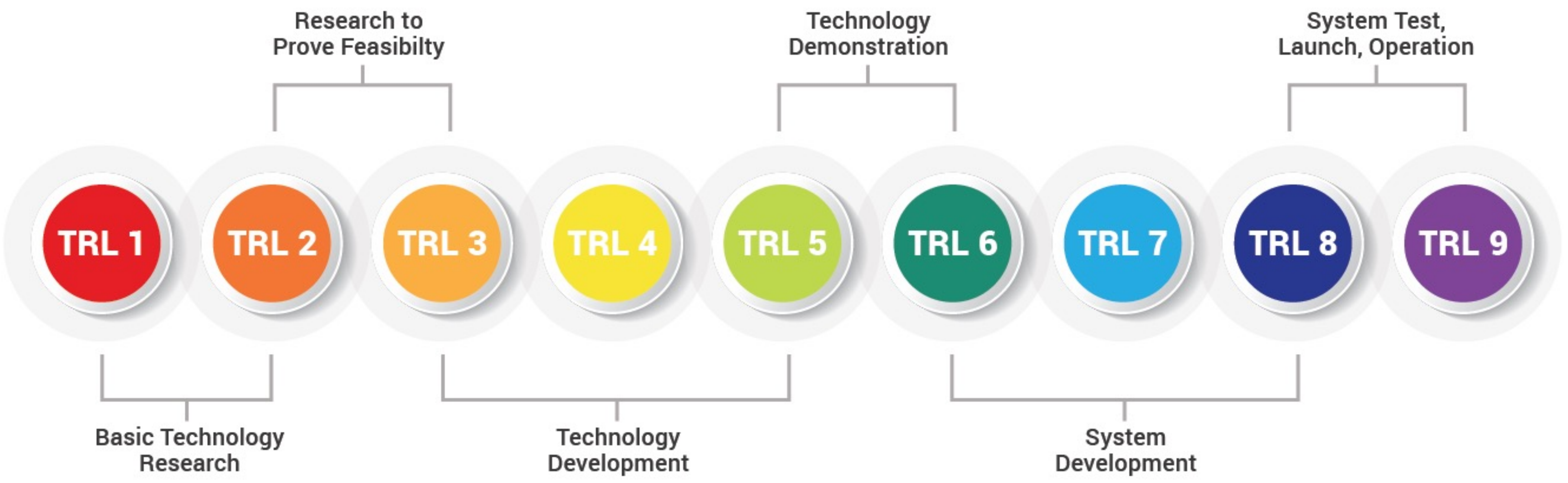
PM effort: INNO 35, BTG 8.4, FCO 14

TRL 4-5 → TRL6

Technology **validated** in lab - Technology **validated** in relevant environment

↓

Technology **demonstrated** in relevant environment



WP6 objectives

- **To optimize formulations** based on Fast Pyrolysis Bio-oil (FPBO) for use as a wood modification agent ✓
- **To characterize the properties** of modified wood by multiple testing techniques ✓
- **To demonstrate the technical feasibility** of the manufacturing line by producing large quantities of modified wood for demo activities and as a raw material for highly durable and sustainable particle boards and to demonstrate circularity

Schema of the workflow

Work in progress

10 formulation

impregnation

curing

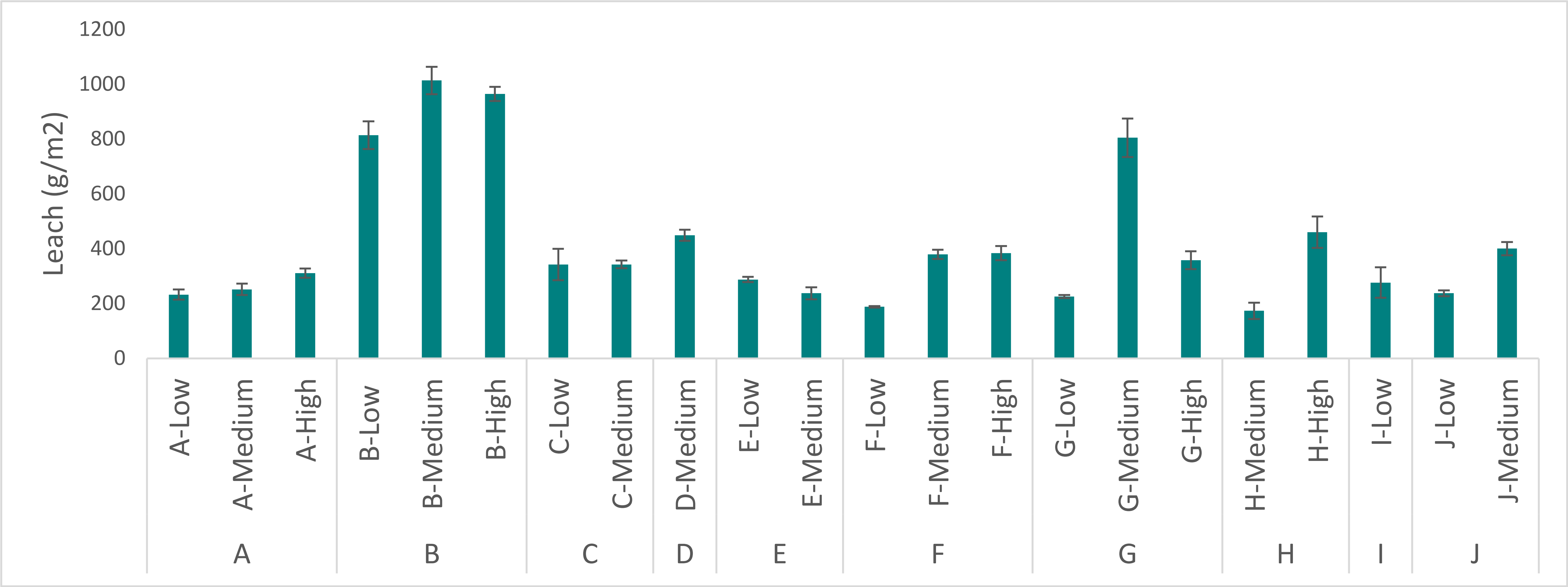
modified wood

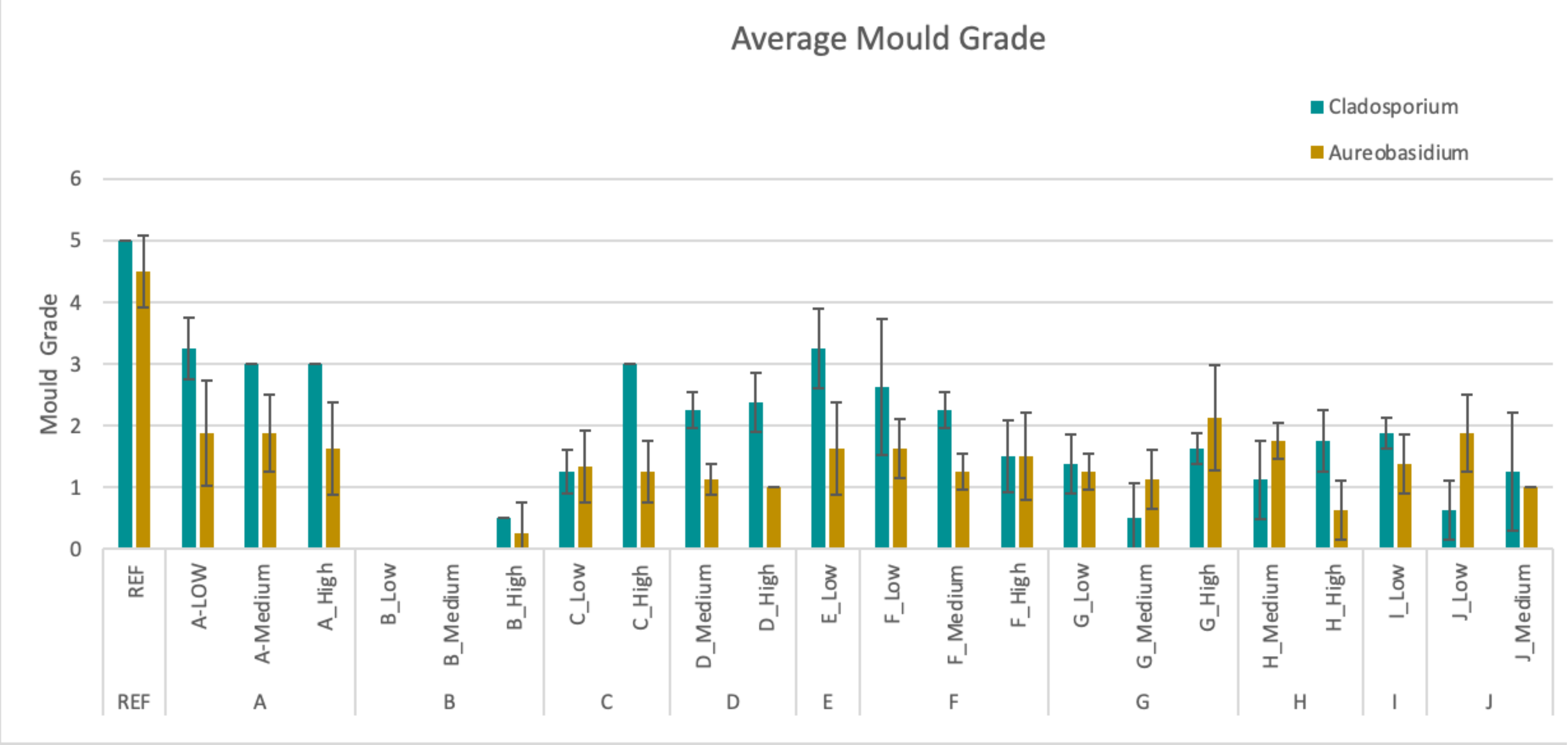
Task 6.3: Description and results

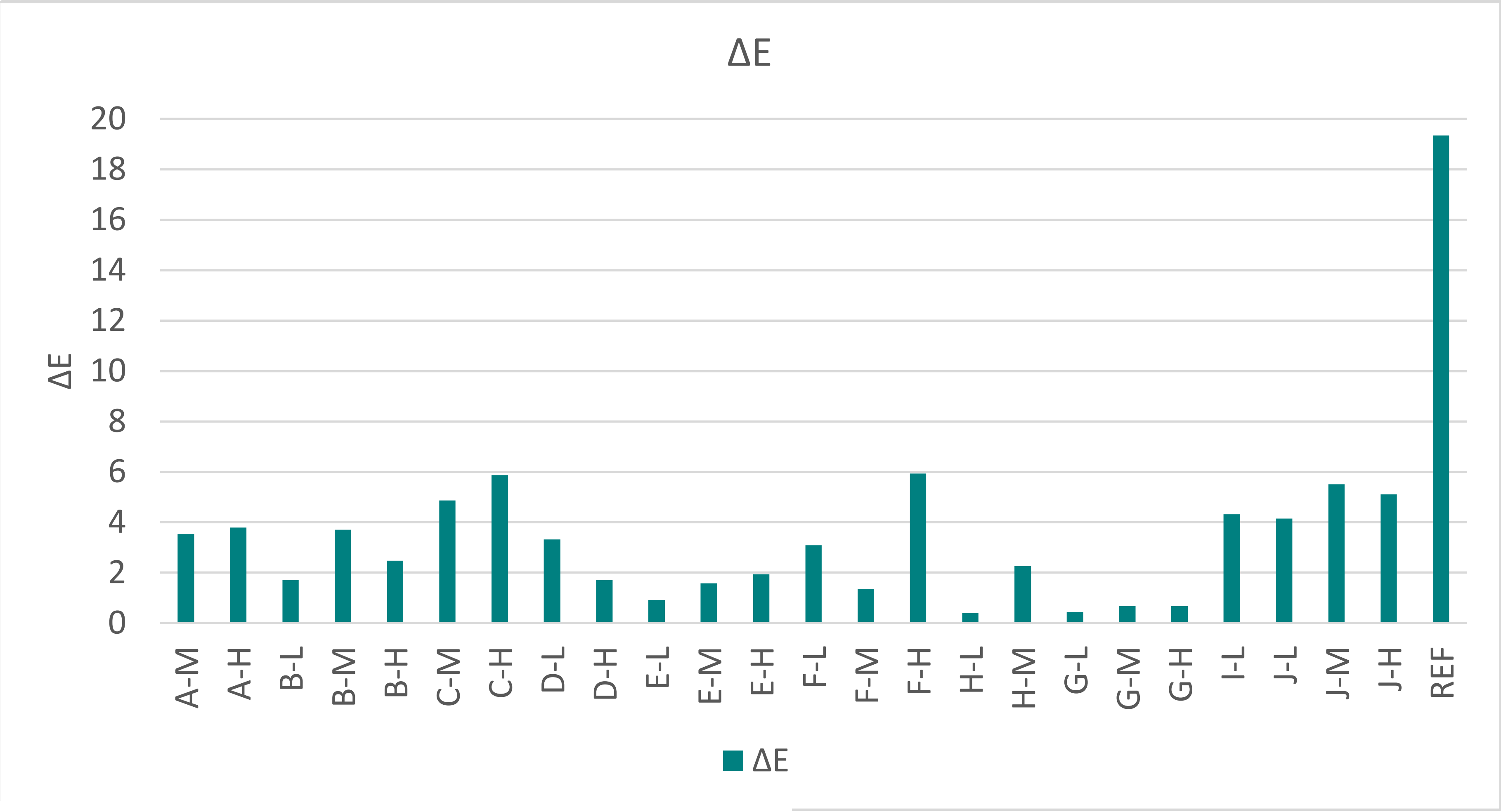
D6.4 Properties of modified wood product

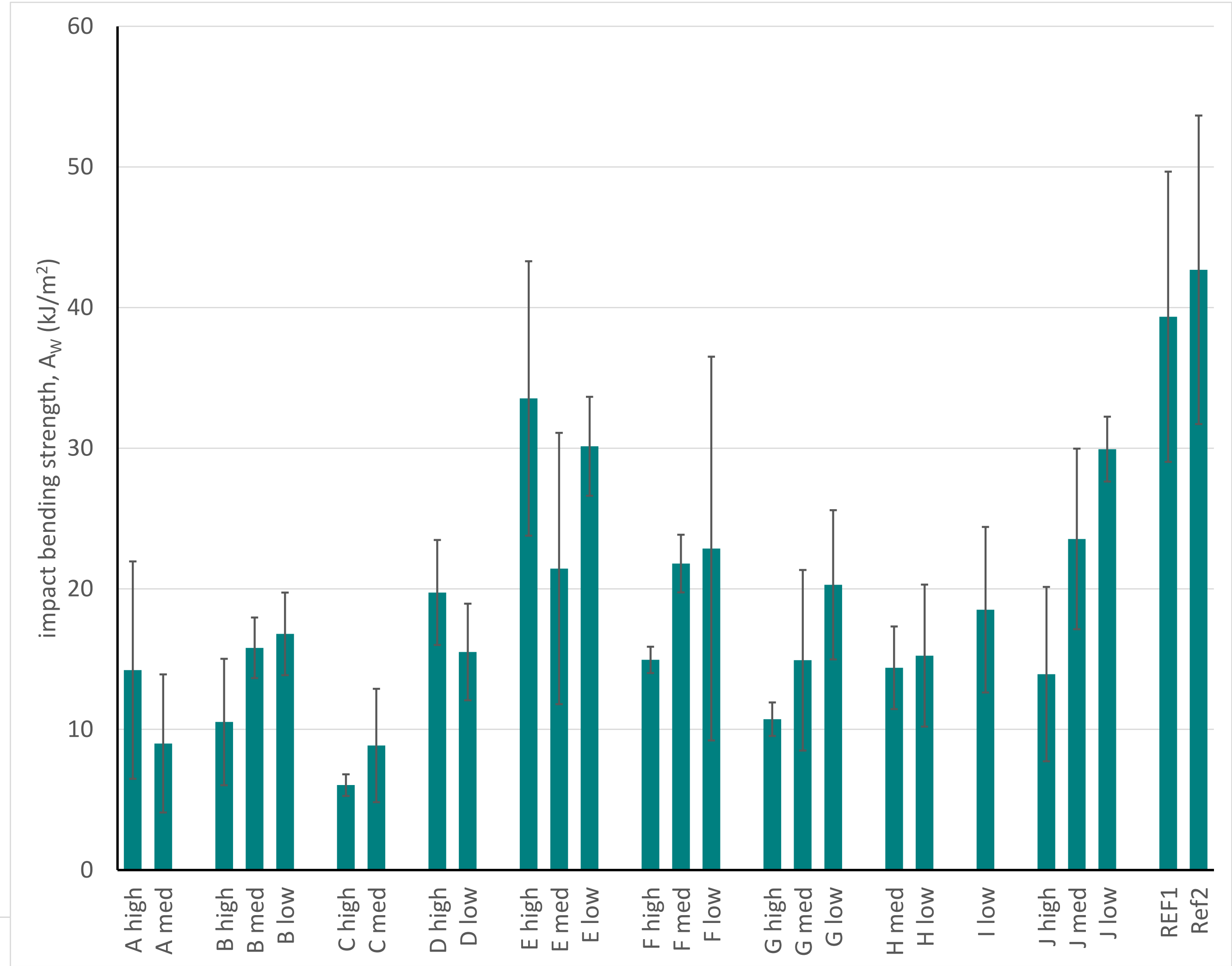
Activity/characterization method	Status
Preparation of specimens for various tests	completed
Samples digitalization	completed
Uptake of impregnation liquor	completed
Density	completed
Moisture uptake	completed
Leaching test	completed
Dimensional stability	completed
Mechanical performance – impact bending strength	completed
UV stability	completed
Biological durability	completed
VOCs emission	completed
Wettability	completed
Appearance (color and gloss)	completed
Hyperspectral imaging	completed
Hygroscopic properties	completed
Thermal properties	completed

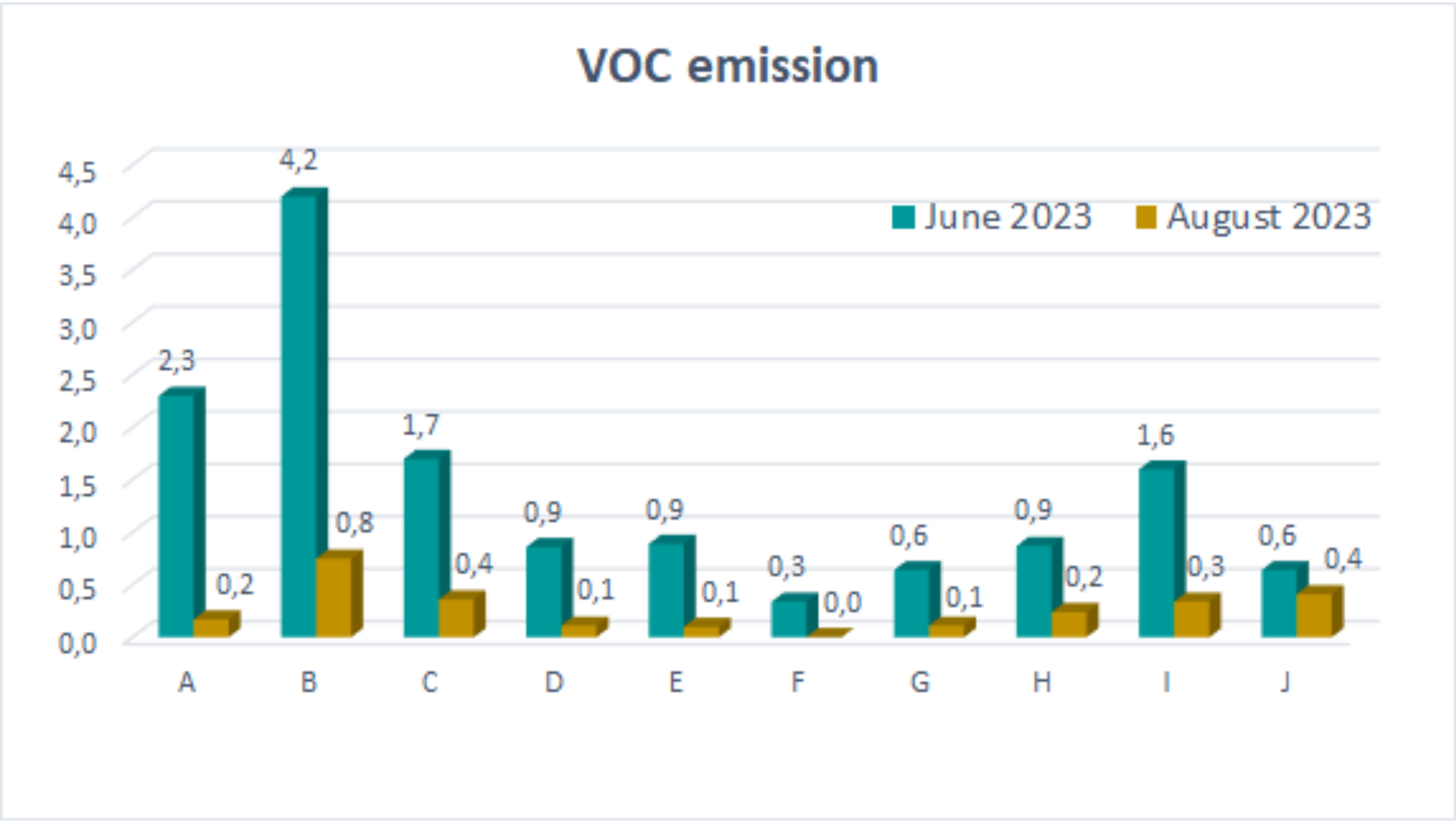

150 mL
RASOTHERM
KIMAX
F9-H-2
F20-H-2
D30

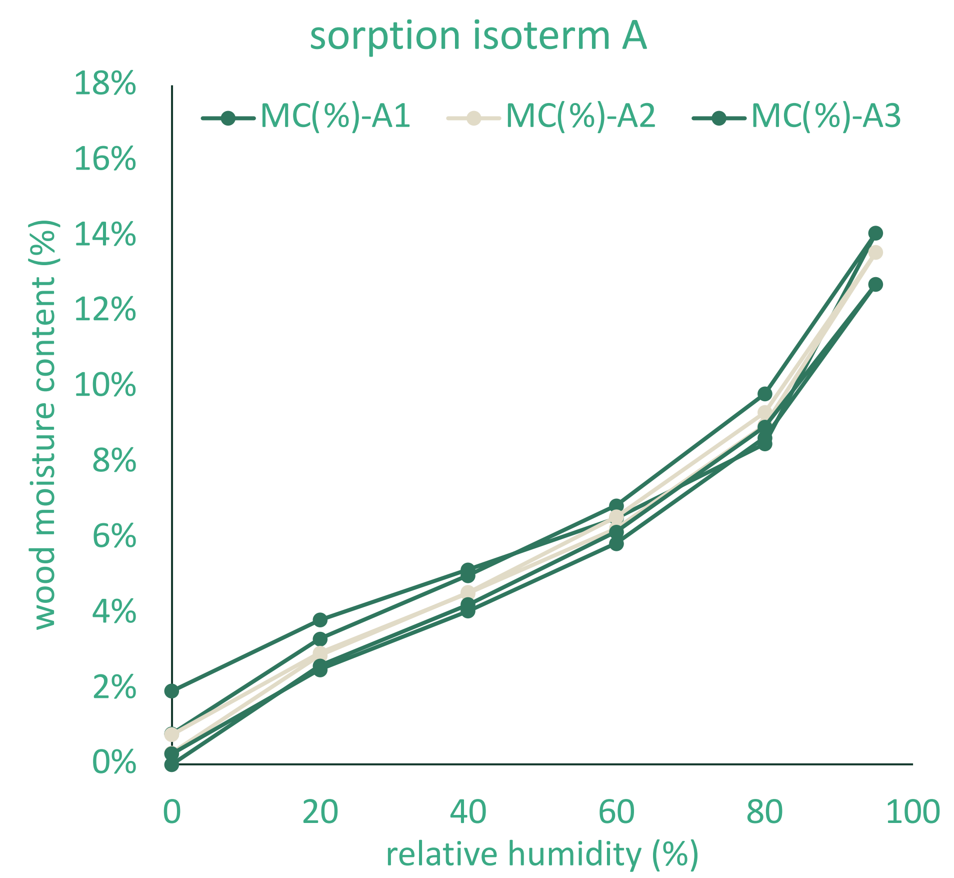

Leach (g/m2)
A-Low
A-Medium
A-High
B-Low
B-Medium
B-High
C-Low
C-Medium
D-Medium
E-Low
E-Medium
F-Low
F-Medium
F-High
G-Low
G-Medium
G-High
H-Medium
H-High
I-Low
J-Low
J-Medium

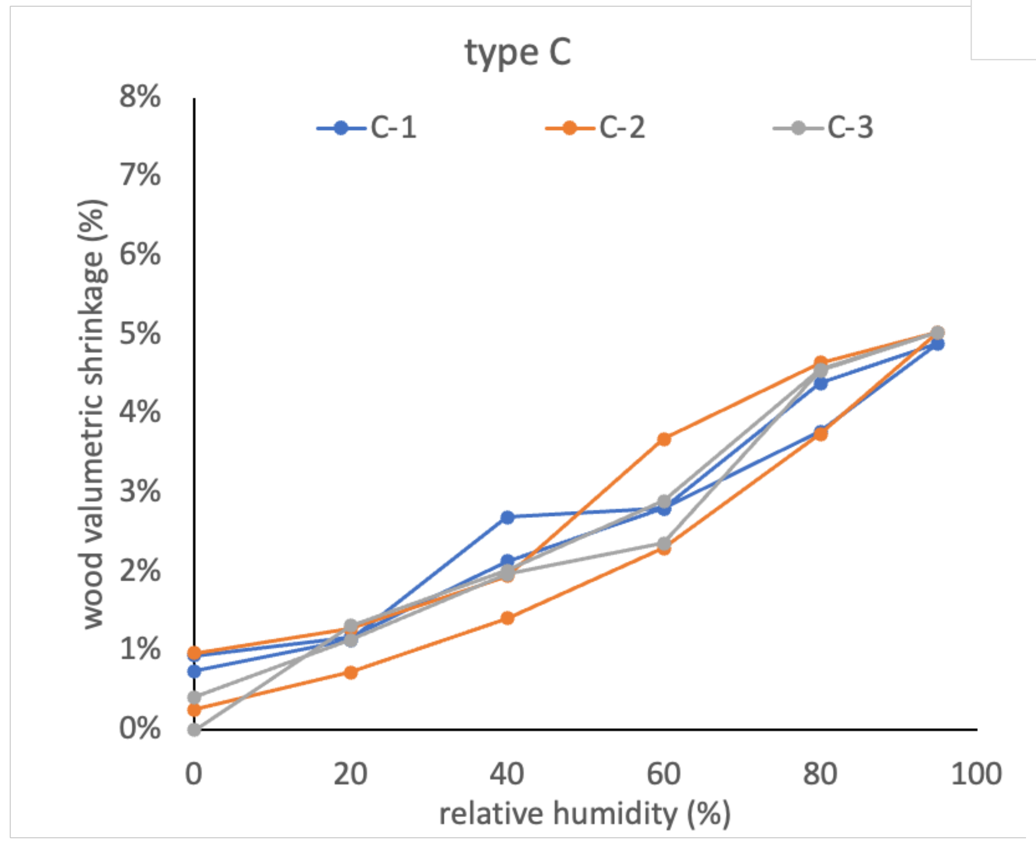

Average Mould Grade
Cladosporium
Aureobasidium
Mould Grade

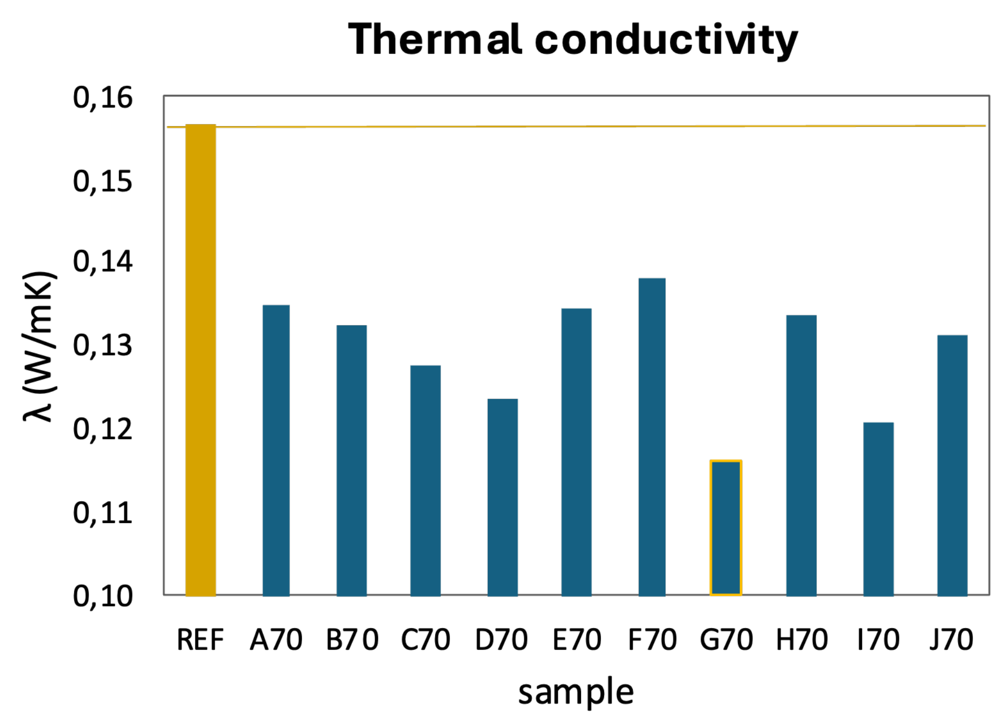

ΔE

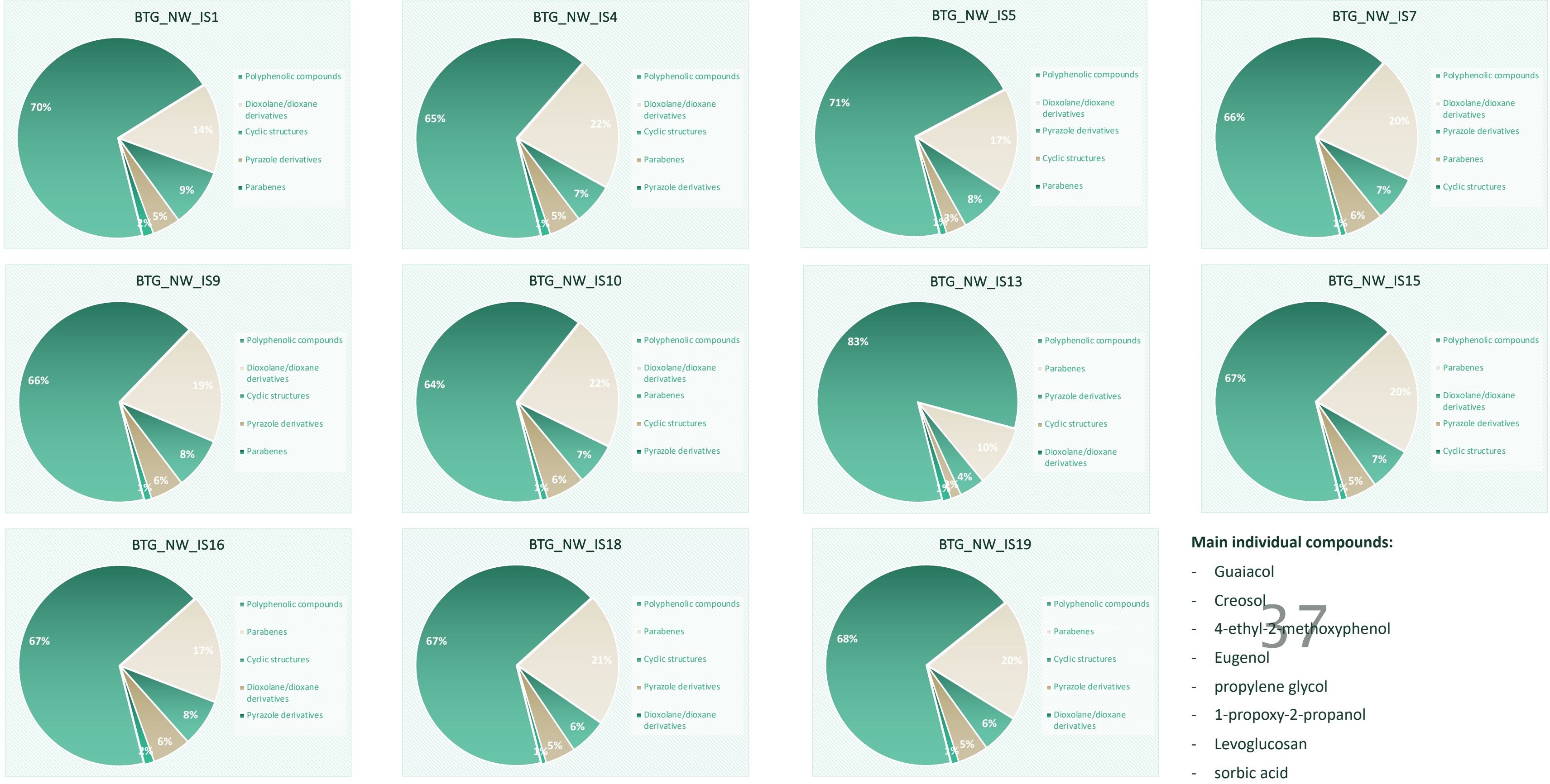

impact bending strength, A_W (kJ/m²)


VOC emission
June 2023
August 2023


sorption isoterm A
MC(%)-A1
MC(%)-A2
MC(%)-A3
wood moisture content (%)
relative humidity (%)


type C
C-1
C-2
C-3
wood valumetric shrinkage (%)
relative humidity (%)

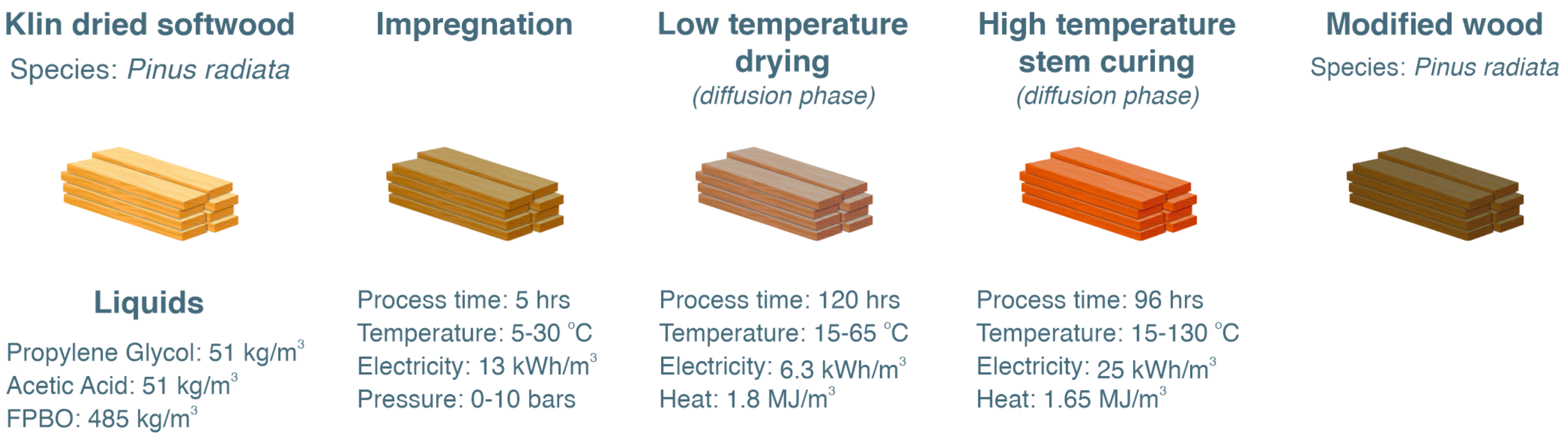

Thermal conductivity
λ (W/mK)
REF
A70
B70
C70
D70
E70
F70
G70
H70
I70
J70
sample


BTG_NW_IS1
BTG_NW_IS4
BTG_NW_IS5
BTG_NW_IS7
BTG_NW_IS9
BTG_NW_IS10
BTG_NW_IS13
BTG_NW_IS15
BTG_NW_IS16
BTG_NW_IS18
BTG_NW_IS19
Main individual compounds:
Guaiacol
Creosol
4-ethyl-2-methoxyphenol
Eugenol
propylene glycol
1-propoxy-2-propanol
Levoglucosan
sorbic acid

	Characterization method	REF	A	B	C	D	E	F	G	H	I	J
	Appearance (color)											
!	Fixation rate (%)		😐	☹	🙂	😐	🙂	🙂	😐	🙂	🙂	🙂
!	Dimensional stability -volumetric shrinkage (%)		😐	🙂	🙂	🙂	😐	😐	😐	🙂	😐	😐
	Hygroscopic properties - EMC at the fibre saturation point (97%RH) (%)		😐	😐	😐	😐	🙂	🙂	🙂	🙂	😐	😐
	Impact bending strength (kJ/m^2)		😐	😐	☹	😐	🙂	😐	😐	😐	😐	🙂
!	Contact angle H_2O (°)		🙂	☹	🙂	🙂	🙂	🙂	🙂	🙂	🙂	😐
	Surface energy γtot [mN/m]		☹	😐	☹	😐	😐	😐	🙂	🙂	🙂	🙂
!	UV stability color (ΔE)		😐	🙂	😐	🙂	🙂	🙂	🙂	🙂	😐	😐
	UV stability gloss (ΔE)		🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	😐	😐
!	Durability class (*Rhodonia*)		🙂	😐	😐	😐	😐	😐	😐	🙂	😐	😐
!	Durability class (*Trametes*)		🙂	😐	😐	😐	🙂	😐	😐	🙂	😐	🙂
	Mold index (*Cladosporium*)		😐	🙂	😐	😐	😐	😐	🙂	😐	😐	🙂
!	Mold index (*Aureobasidium*)		😐	🙂	🙂	🙂	😐	🙂	😐	🙂	😐	🙂
	VOCs emission (% reduction)		🙂	☹	😐	🙂	🙂	🙂	🙂	😐	😐	☹
	Thermal conductivity λ (W/mK)		😐	😐	😐	🙂	😐	😐	🙂	😐	🙂	😐

LCA/LCC and Business feasibility

- Transport of raw material/ sawn wood to the production site
- Modification process:
  - Impregnation:
    - Liquid solution
    - Electricity - energy for impregnation
    - Waste liquid solution
    - Emissions
  - Low temperature drying:
    - Electricity - energy use
    - Heat - energy use
    - Emissions
  - High-temperature steam curing:
    - Electricity - energy use
    - Heat - energy use
    - Emissions
- Packaging at the production site
  - Packaging material use
  - Waste of packaging material



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Thank you!

New Wave Project

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