

IUPAC | CCCE 2021 Virtual • August 13 - 20, 2021

IUPAC | CCCE 2021

Solving Global Challenges with Chemistry



Endorsed by:



Symposium: **Systems Thinking in Chemistry Education**

18 August 2021

Paper No 1502

Sustainability of paper and paperboard as a contextual approach to applying systems thinking in chemistry education

Stephen A. Matlin*

s.matlin@imperial.ac.uk



Chemists for Sustainability



**International Organization for
Chemical Sciences in Development**

IOCD

**Imperial College
London
Institute of Global Health Innovation**

Peter G. Mahaffy

www.kcvs.ca



Klaus Kümmerer

klaus.kuemmerer@uni.leuphana.de

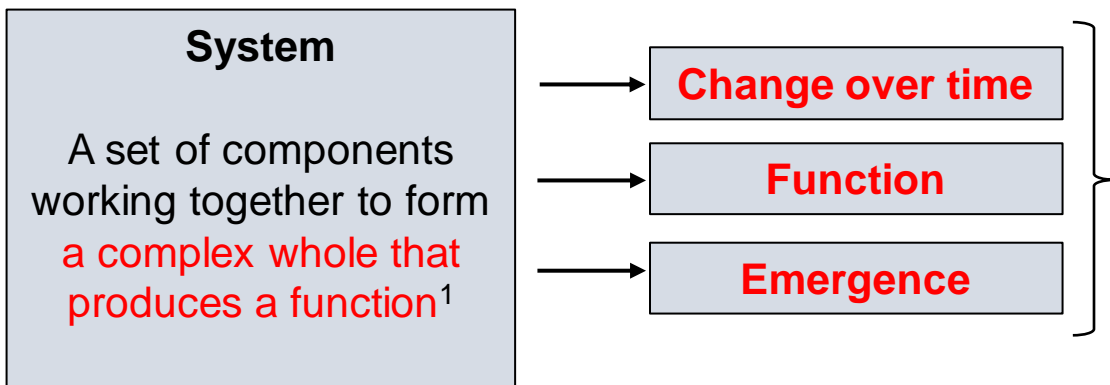
**Institute for
Sustainable Chemistry**



LEUPHANA
UNIVERSITY LÜNEBURG

Systems Thinking

- One of the **key competencies** essential for achieving sustainability¹
Core skill = ability to analyse, understand and interpret complex systems²



Function

Object – e.g. clock to tell the time

Process – e.g. company's management system

Emergence

➤ An overall function or effect that cannot be deduced or produced from the isolated parts separately

➤ **Sustainability** is a property of the whole system – it is not simply a property of individual elements of the system³

The **chemical sciences** have been central to global progress and **will be essential to meeting oncoming global challenges** – especially sustainable development – **with 'one-world' chemistry**⁴

Requires: cross-disciplinary ('convergent') approaches
systems thinking

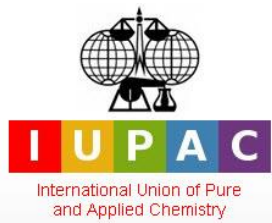
Building the necessary skills and competencies must begin with **chemistry education**.

¹ A. Wiek, L. Withycombe, C.L. Redman. *Sustainability Sci.* 2011, 6, 203–218, <https://doi.org/10.1007/s11625-011-0132-6>

² D. H. Meadows, . *Thinking in Systems: A Primer*. Earthscan, London 2009. <https://wtf.tw/ref/meadows.pdf>

³ F. Ceschin, I. Gaziulusoy. *Design Studies* 2016, 47, 118-163, <https://doi.org/10.1016/j.destud.2016.09.002>

⁴ S.A. Matlin, G. Mehta, H. Hopf, A. Krief. *Nature Chemistry* 2016, 8, 393-396, <https://doi.org/10.1038/nchem.2498>



Infusing **S**ystems **T**hinking into
(Post)-Secondary General **C**hemistry **E**ducation
STICE¹

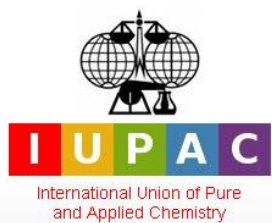
Supported by



Journal of Chemical Education 2019, vol 96: Special Themed Issue
Reimagining Chemistry Education: Systems Thinking and Green and Sustainable Chemistry^{2,3}

Development of a new visualization tool to assist in teaching, learning and practicing ST in chemistry
Systems-Oriented Concept Map Extension **SOCME**⁴

SOCME guides the analysis process, encouraging thinking about where **all** the materials and energy come from, where they go and what effects they may have; **helps identify sensitive areas** where major sustainability challenges arise; and **supports questioning about and exploration of alternatives**



Systems **T**hinking in **C**hemistry for **S**ustainability: Toward **2030** and
Beyond (**STCS 2030+**)⁵

Supported by



¹ IUPAC Project # 2017-010-1-050 Co-chairs: P.G. Mahaffy, S. A. Matlin https://iupac.org/projects/project-details/?project_nr=2017-010-1-050

² J. Chem. Educ. 2019, vol 96: <https://pubs.acs.org/toc/jceda8/96/12>

³ P.G. Mahaffy, S.A. Matlin. Next hundred years: Systems thinking to educate about the molecular basis of sustainability. *L'Actualité Chimique* 2019, 446,47-49. <https://www.lactualitechimique.org/Pour-les-cent-ans-a-venir-reflexions-sur-l-enseignement-de-la-chimie-et-la-durabilite>

⁴ P.G. Mahaffy, S.A. Matlin, T.A. Holme, J. MacKellar. *Nature Sustainability* 2019, 2, 362-370, <https://doi.org/10.1038/s41893-019-0285-3>
K.B. Aubrecht, Y.J. Dori, T.A. Holme, R. Lavi, S.A. Matlin, M. Orgill, H. Skaza-Acosta. *J Chem Educ* 2019, 96, 2888-2900, <https://doi.org/10.1021/acs.jchemed.9b00314>

⁵ IUPAC Project # 2020-014-3-050 Co-chairs: P.G. Mahaffy, S.A. Matlin, M. Potgieter, B.B.Saha A.P. Visa <https://iupac.org/project/2020-014-3-050>

Paper and paperboard: products of wood pulp¹

“Paper is one of the few truly sustainable products.”

“The myth that paper is bad for the environment”

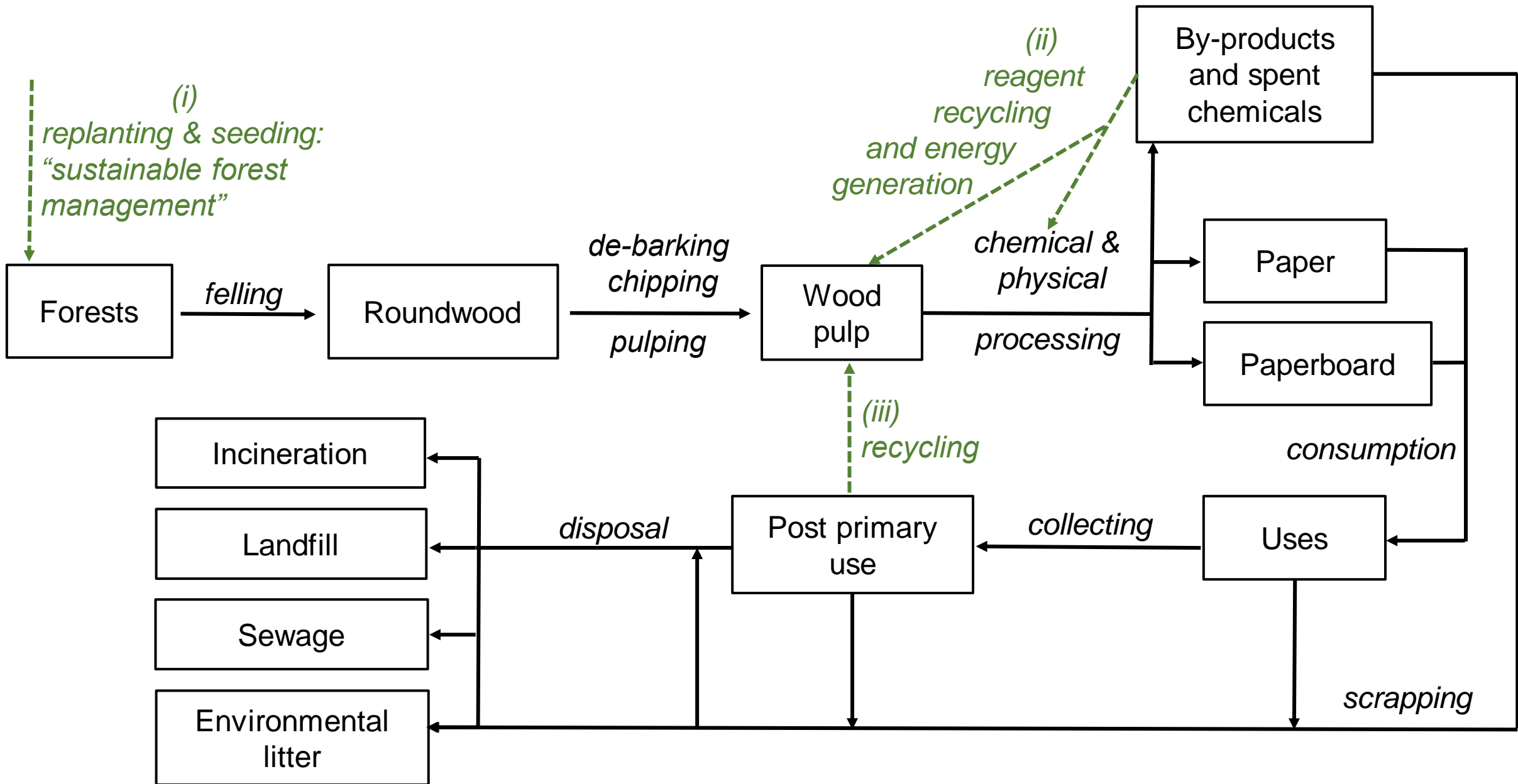
Two Sides, 2020

<https://www.twosides.info/sustainable-products/>

“Paper is one of the few products which is completely sustainable.” FESPA, 2018

<https://www.fespa.com/en/news-media/features/sustainability-and-paper-what-are-your-options>

¹ S.A. Matlin, K. Kümmerer, P.G. Mahaffy. *Mapping complex cross-system sustainability effects: the sustainability of paper and paperboard*. In: E. Michalopoulou, T. Stanmore, L. Ma. N. Jester, E.D. Shallcross, E. Atkins, W. Leal Filho (eds), *Sustainability and complexity: towards a post-disciplinary approach*. World Sustainability Series, Springer, 2021, **submitted**.

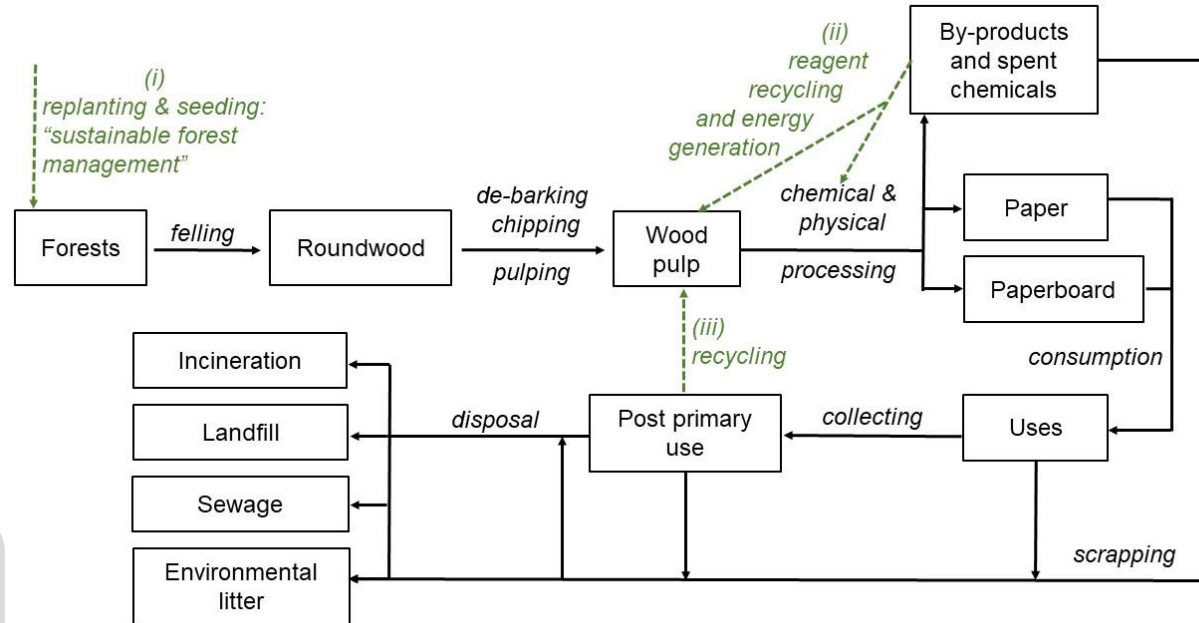


ATMOSPHERIC SYSTEM

LAND SYSTEM

AQUATIC SYSTEM

ENERGY INPUT SYSTEM



BIOLOGICAL & ECOLOGICAL SYSTEMS

MATERIAL INPUT SYSTEM

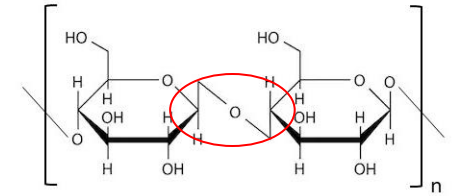
HUMAN SYSTEM

- ✓ **Combustion**
 - **Oxidation**

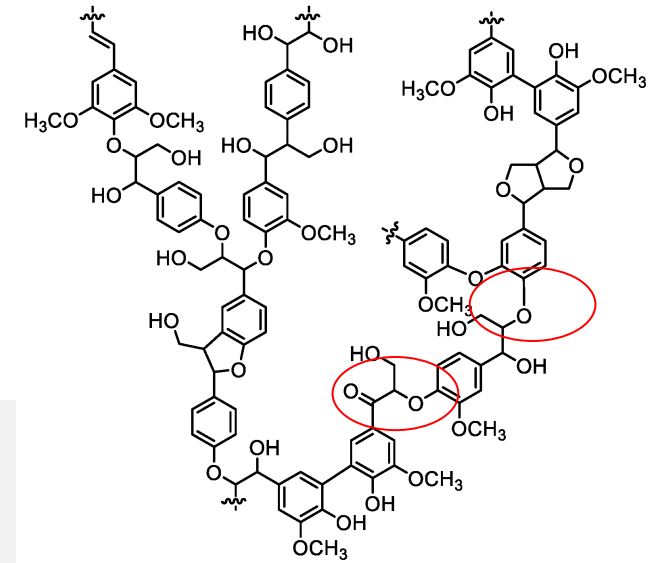


Cellulose

n = approx. 10,000

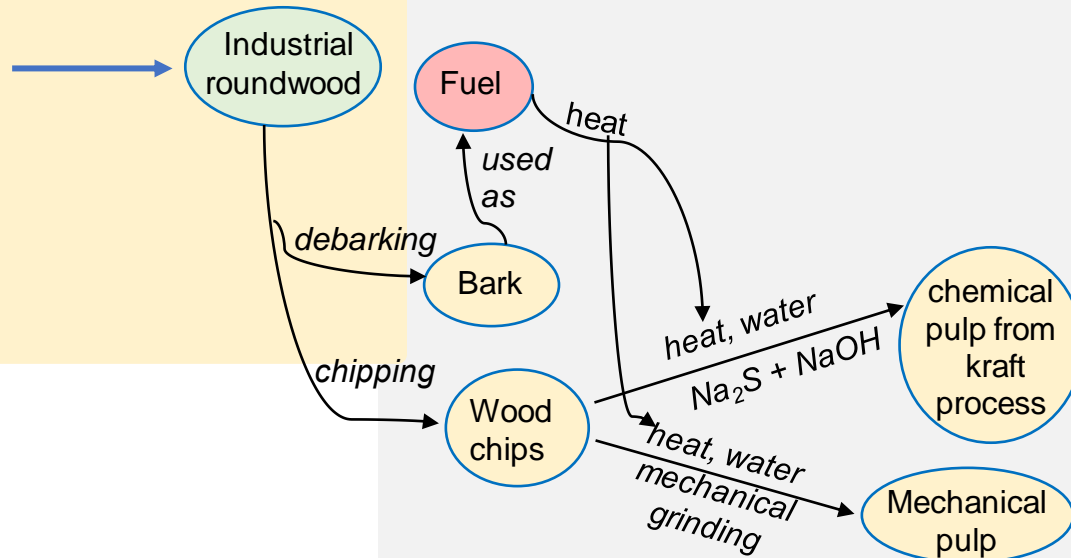


Representative structure of lignin



WOOD PULP TO PAPER

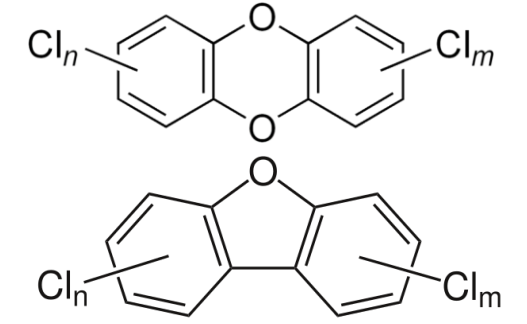
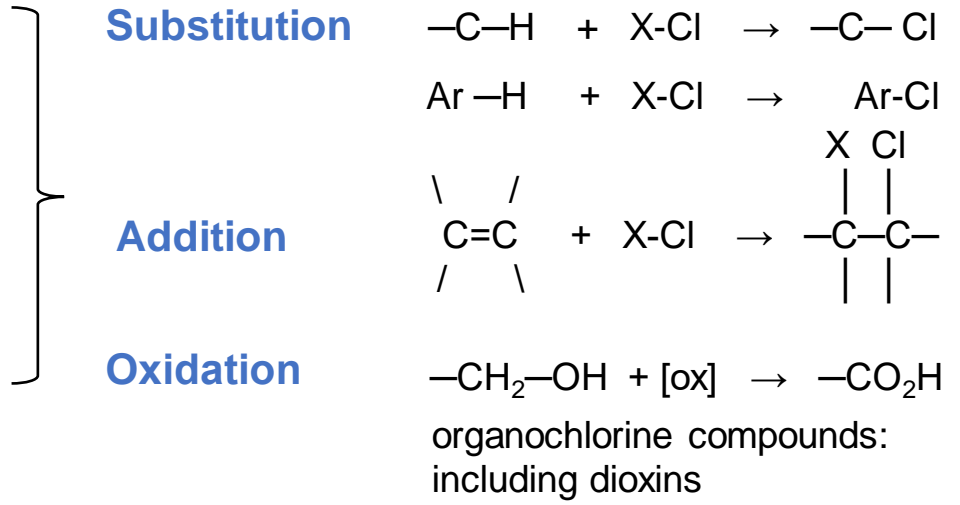
Tree felling for wood pulp:
~ 4 billion trees/yr



1. WOOD SOURCES

✓ **Bleaching**

- Sodium hypochlorite (NaOCl) or elemental chlorine (Cl₂)
 $Cl_2 + H_2O \rightleftharpoons H^+ + Cl^- + HOCl$
- ECF (Elemental Chlorine Free) with chlorine dioxide (ClO₂)
- TCF (Totally Chlorine Free): sequence of, e.g. O₂, O₃, NaOH, NaOOH, sodium dithionite



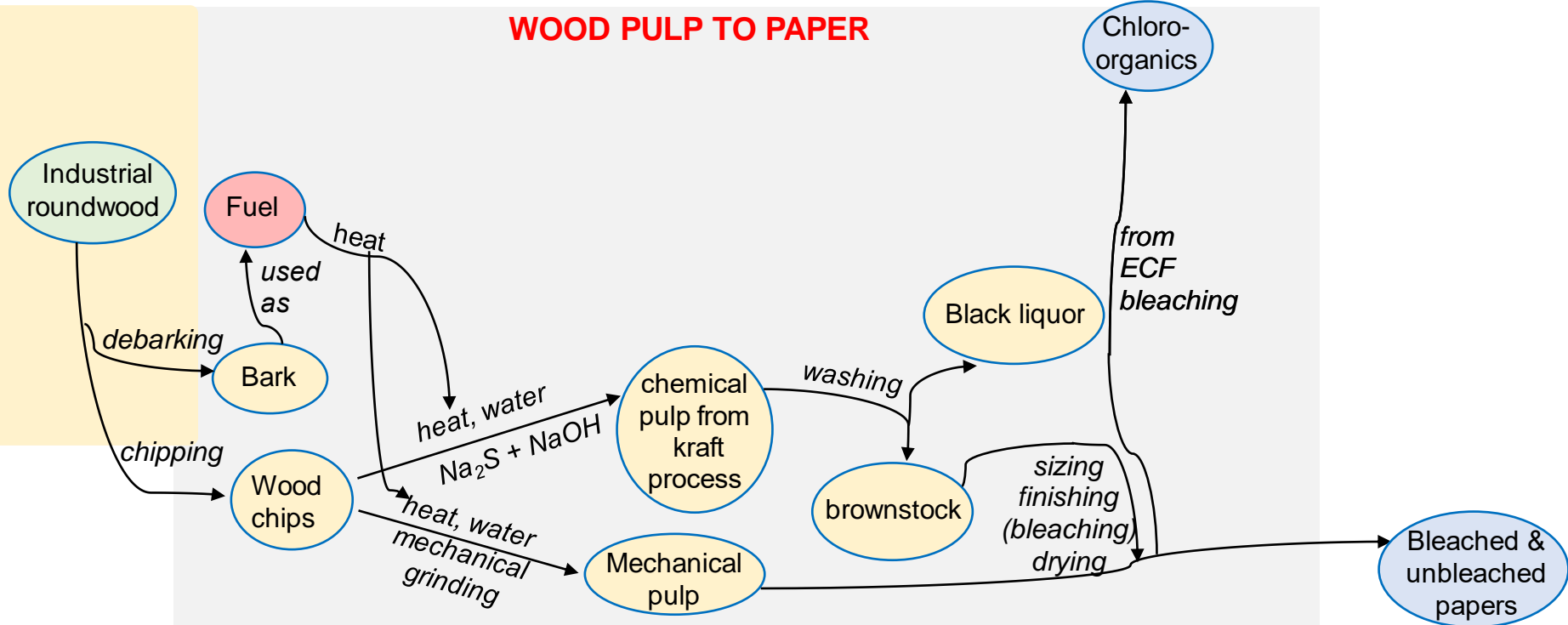
Dioxins

- highly persistent
- tend to concentrate in food chains
- some are potent carcinogens, endocrine-active, neurotoxic

Effluent free from chlorine compounds

Tree felling for wood pulp:
~ 4 billion trees/yr

1. WOOD SOURCES



WOOD PULP TO PAPER

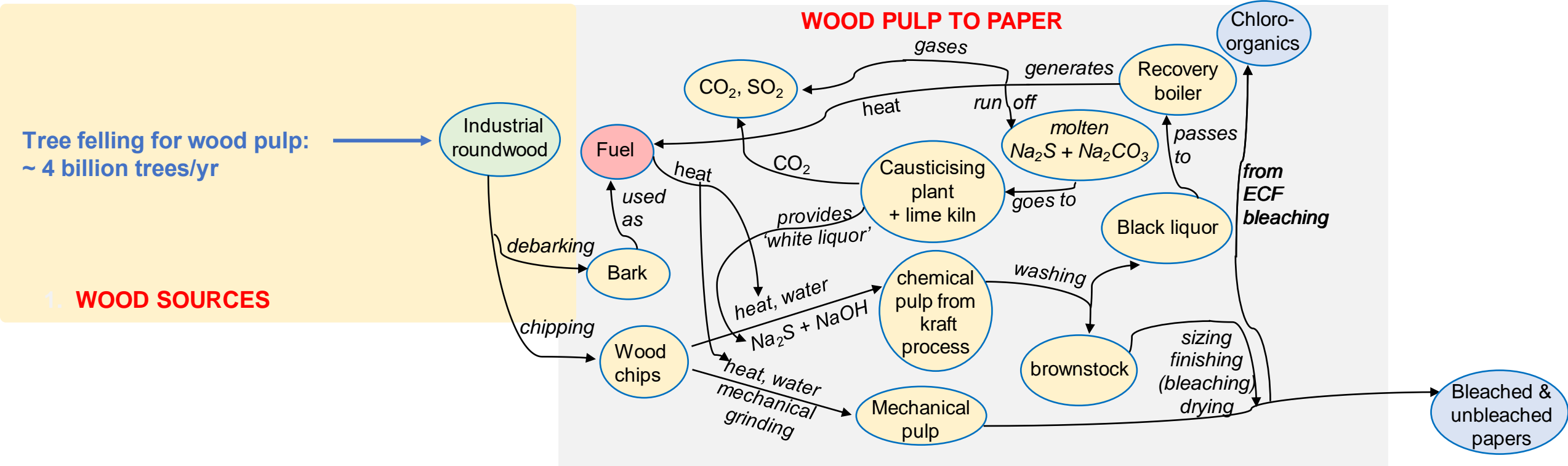
Recovering sodium compounds

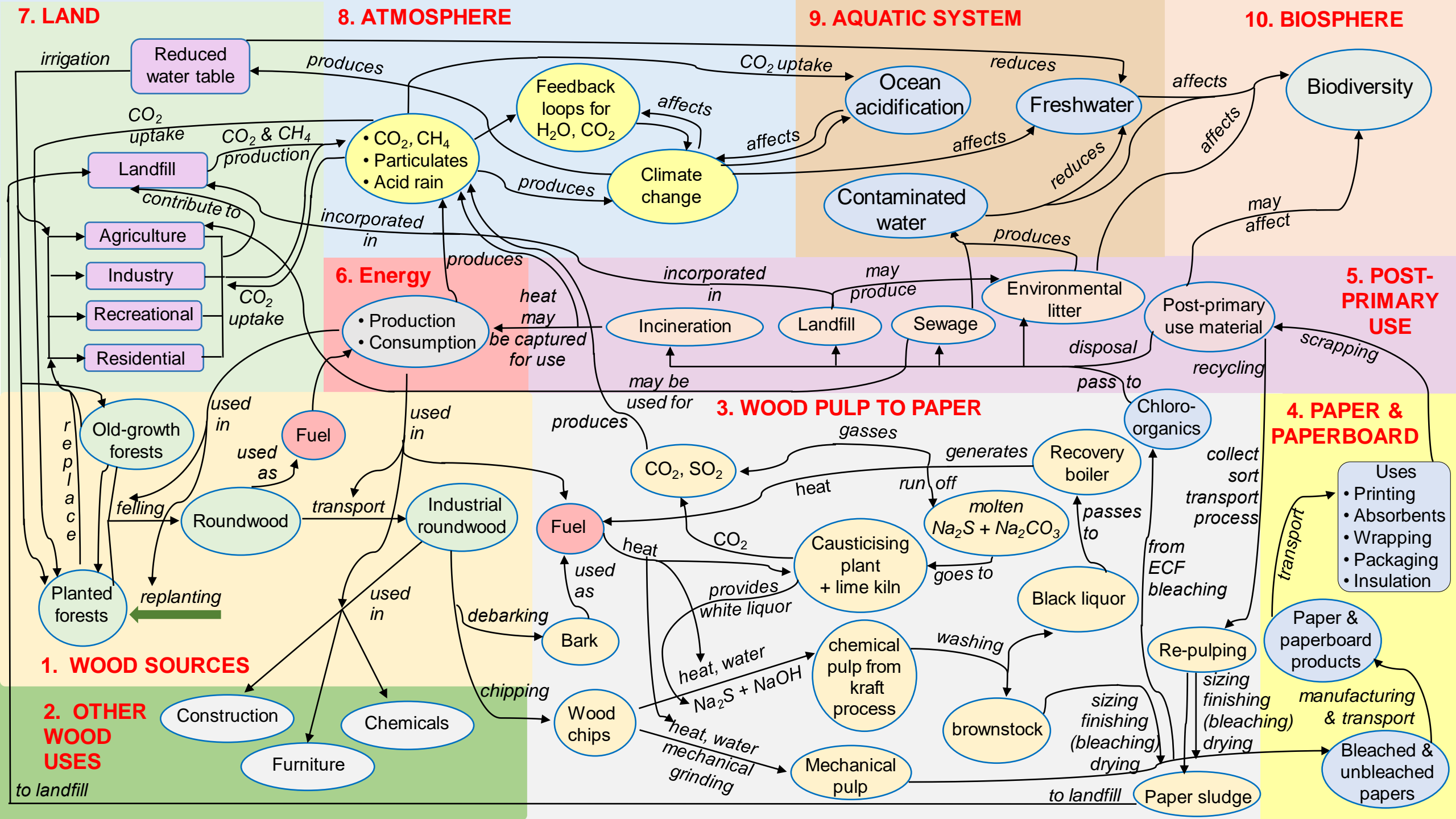
Sodium compounds from combustion stage exit the recovery boiler as a molten inorganic flow of mainly Na_2S and Na_2CO_3

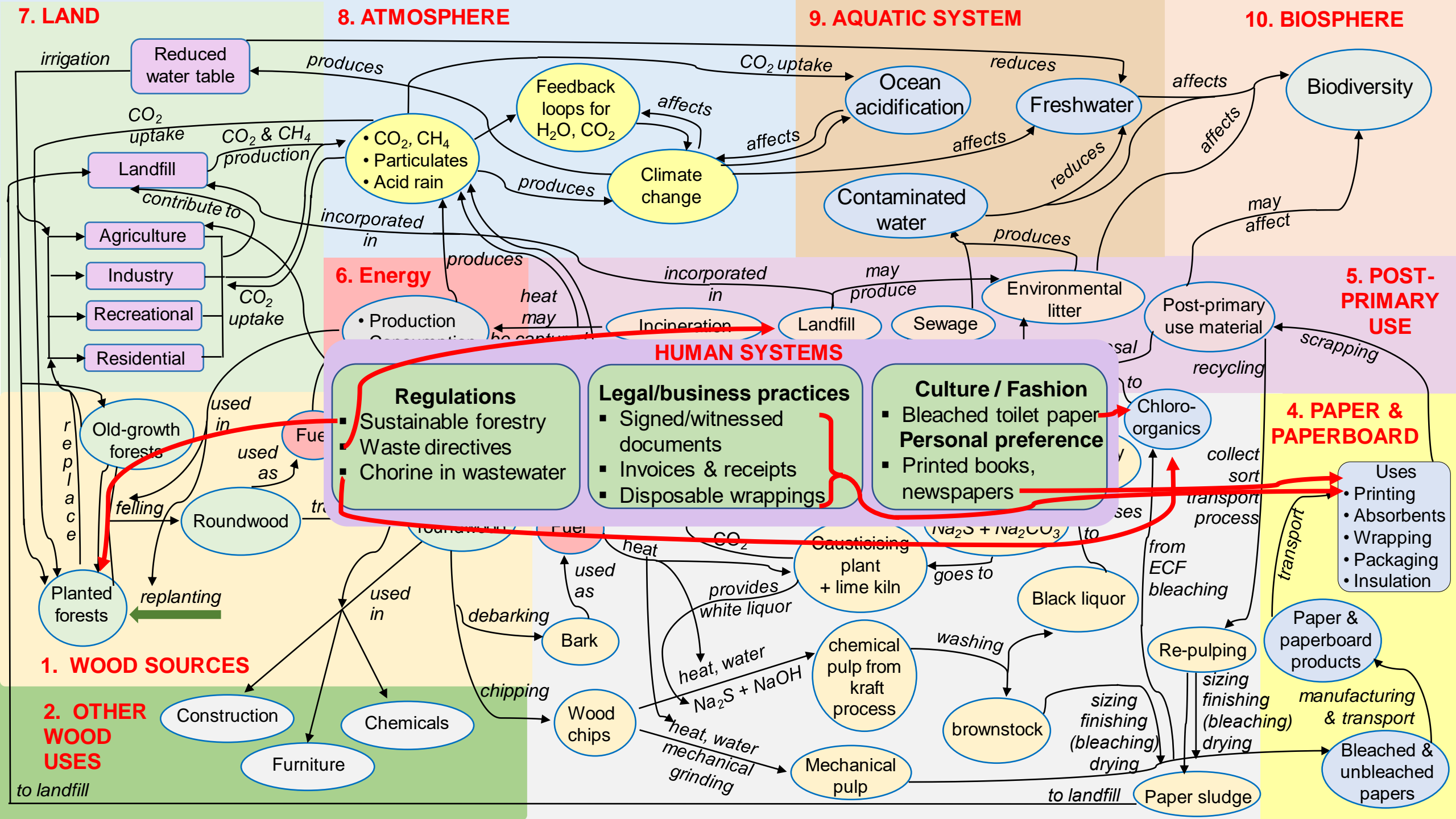
- In dissolving tank, forms a aqueous solution, passed to a causticizing plant, where:

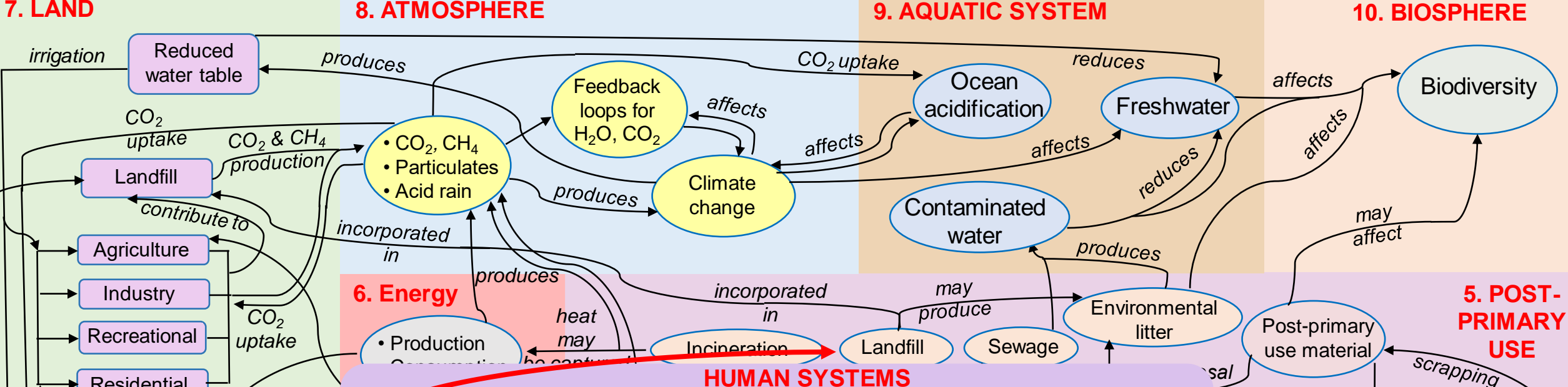


- Regenerates 'white liquor' solution containing Na_2S and NaOH , which is recycled to the kraft process;
- and calcium oxide which is recycled to the lime kiln
- Globally, >200 Mt/year black liquor dry solids are burned in recovery boilers:
 - recovers 96% of Na and 65% of the energy content of black liquor
 - 700 Mt of high-pressure steam produced: black liquor 5th most important fuel in world after coal, oil, natural gas, gasoline
 - large amounts of CO_2 and SO_2 generated









Sustainability is a property of the whole system
 – it is not simply a property of individual elements of the system

