International Conference on Nanotechnology for Renewable Materials

Clean energy: An alternative fuel cell based on sustainable and earth-friendly components

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June 13^{th} 2023.

12-16 JUNE 2023 • VANCOUVER, B.C. CANADA

Outline

- Introduction
- Problem, resolution, and motivation
- Methodology
- General results
- Next steps

Energy source

Fossil based fuel

85 %

Drawbacks

CO_2 emissions

What can be a solution?

CLEAN ENERGY

Electrochemical energy

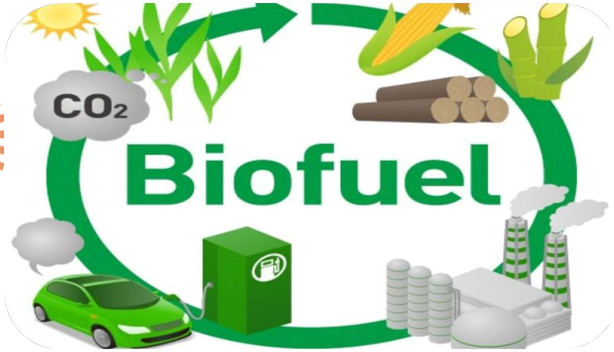
Solar energy

Geothermal energy

Alternatives

Wind energy

Biofuel



FUEL CELL (FC)

A fuel cell uses the chemical energy of hydrogen or other fuels to cleanly and efficiently produce electricity.

Benefits:

- Power density
- Longer lifespan
- Faster start-up
- Cheaper manufacturing costs

Fuel cell type	**PEMFC**
Anode reaction	$H_! \rightarrow 2H^" + 2e^\#$
Cathode reaction	$1/2O_! + 2H^" + 2e^\# \rightarrow H_!O$

Proton Exchange Membrane - PEM

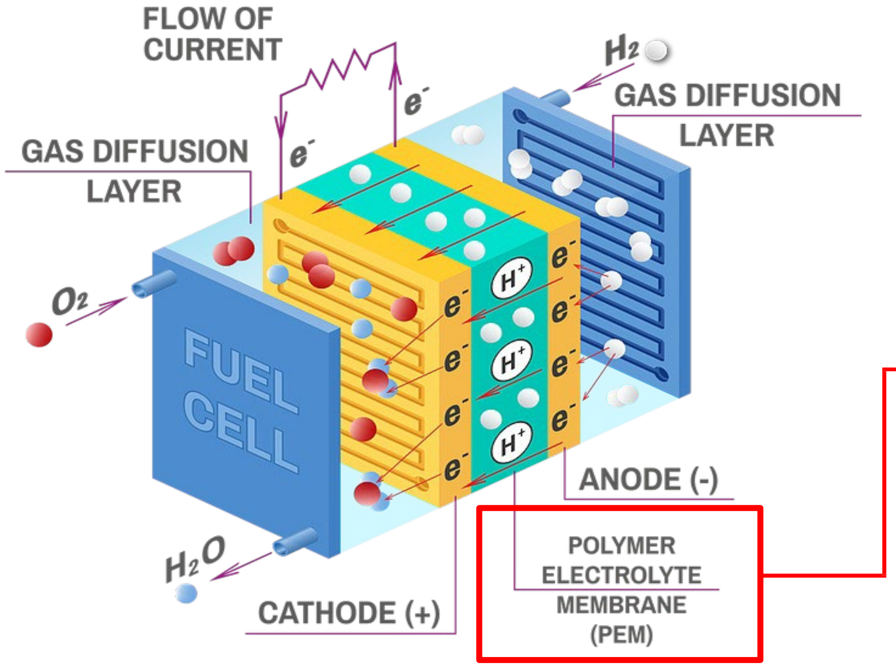


Figure 1. Proton exchange membrane (PEM).(Hickner, 2013).

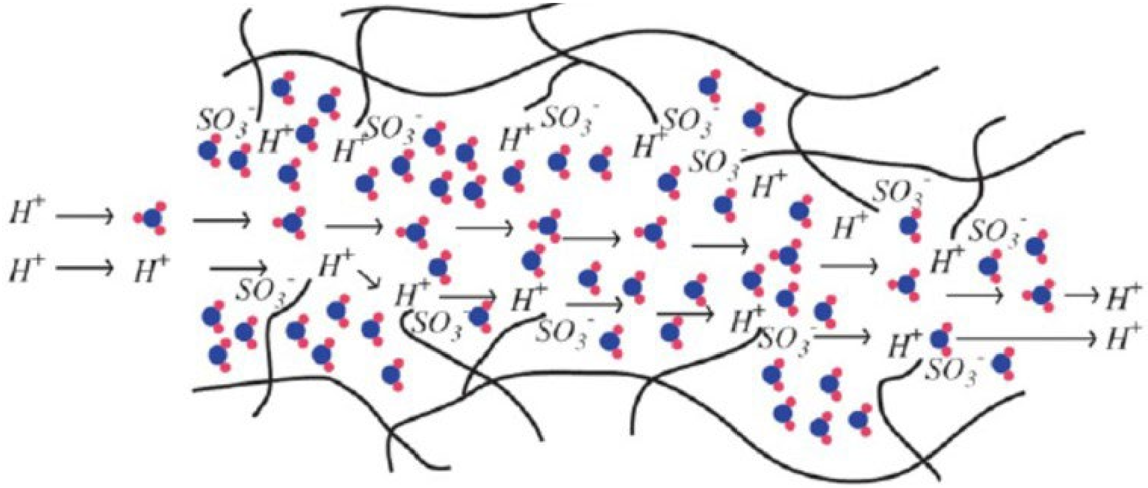


Figure 2. Schematic design of the mechanism of proton conduction in a proton exchange membrane (Rowshanzamir, 2010).

Polymer Exchange Membrane - PEM

H_2 Opportunity

	2030	2050
% of Delivered Energy	6%	30%

Figure 3. Canadian government estimate for future hydrogen production. (Canadian energy strategy, 2020)

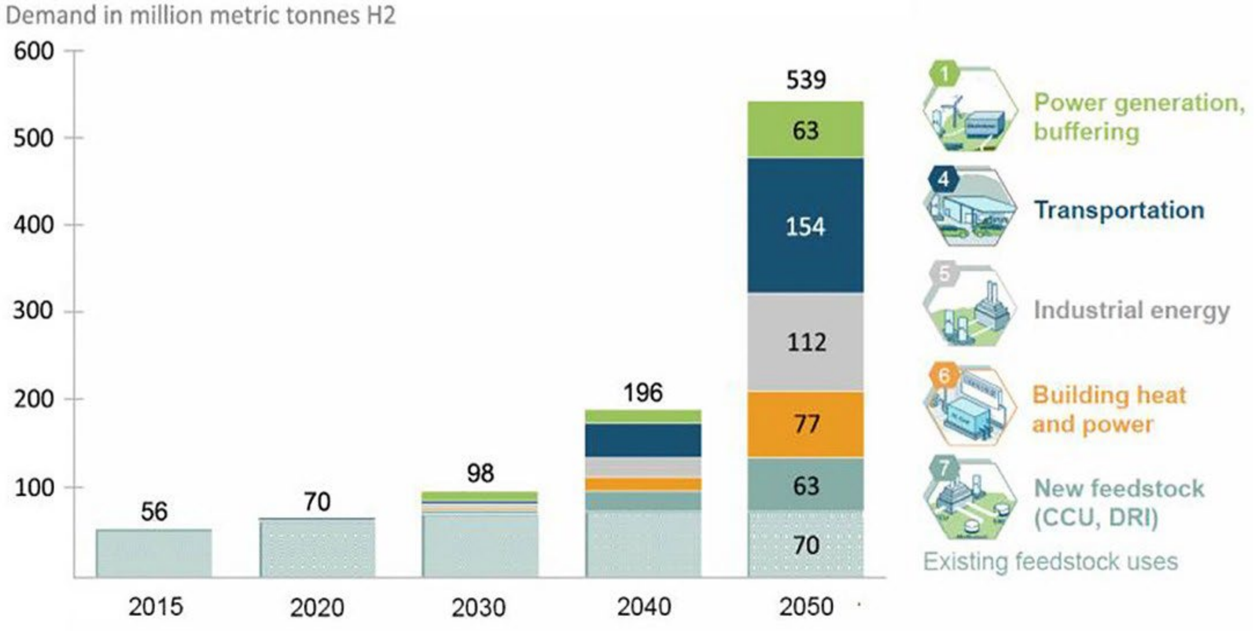


Figure 4. Hydrogen demand projection (EU Hydrogen Council, 2017)

Motivations

I. Hydrogen energy: A rich and promising field of study
II. PEMFCs are expected to be fully commercialized in the next 10-15 years
III. Overcoming critical technical barriers to fuel cell development

Performance → **Durability** → **Cost**

How can we solve these problems?

- Incorporating sustainable materials into the membrane

- Mechanical, thermal, physical, chemical, and electrical properties.

How can we do this?

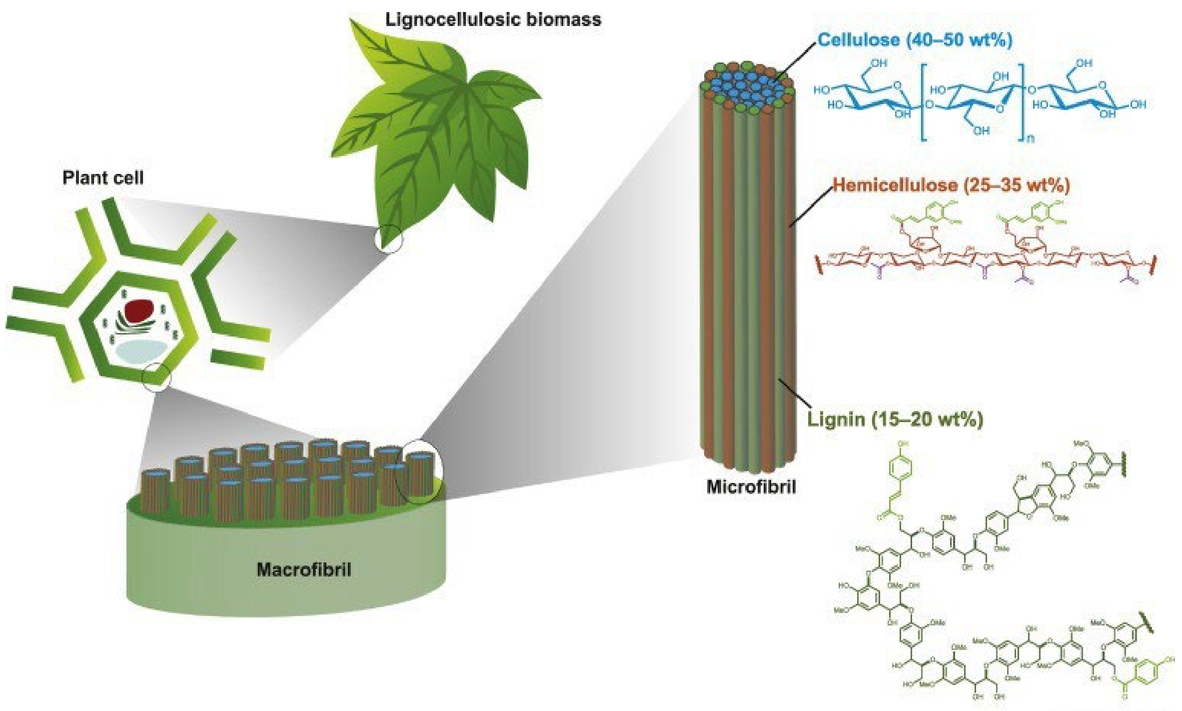
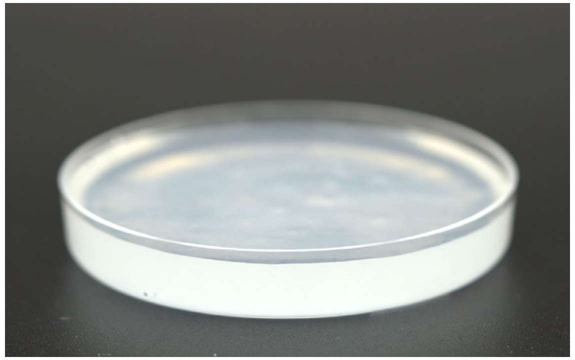
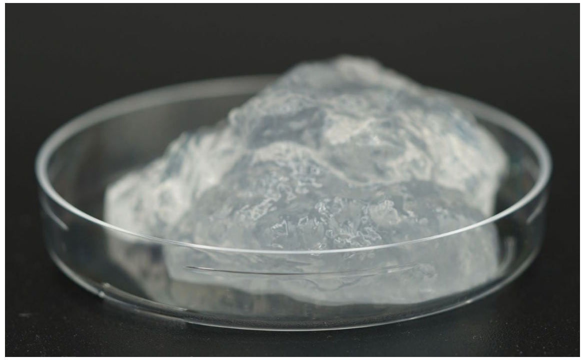


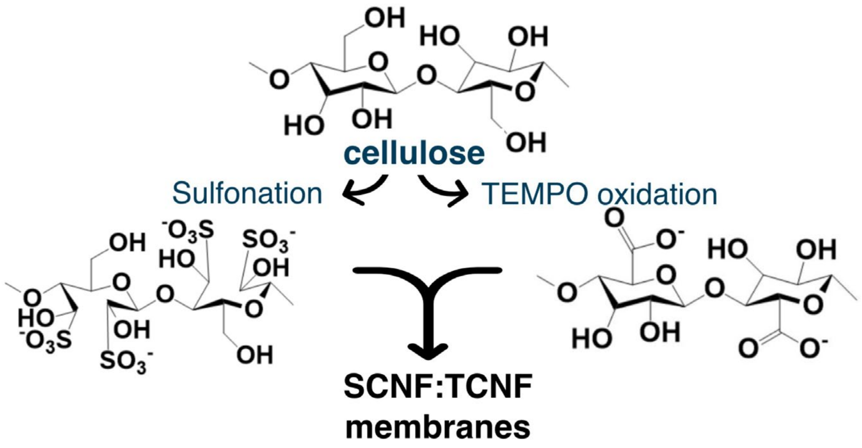
Figure 5. Overview of the structure of lignocellulosic biomass (Bertella, 2020).

1. Study of modified CNF

Methodology







Characterization

Results

Figure 6. Membranes of T-CNF and S-CNF

Results

Table 1. Storage modulus (MPa) of the modified CNF membranes.

Membrane	Storage Modulus (MPa)	
	25°C	80°C
T-CNF	8526	9996
75%T – 25%S	9878	18106
50%T – 50%S	11034	10087
25%T – 75%S	7702	9966
S-CNF	8096	10761

T-CNF = TEMPO nanocellulose fibers
S-CNF = Sulfonated nanocellulose fibers

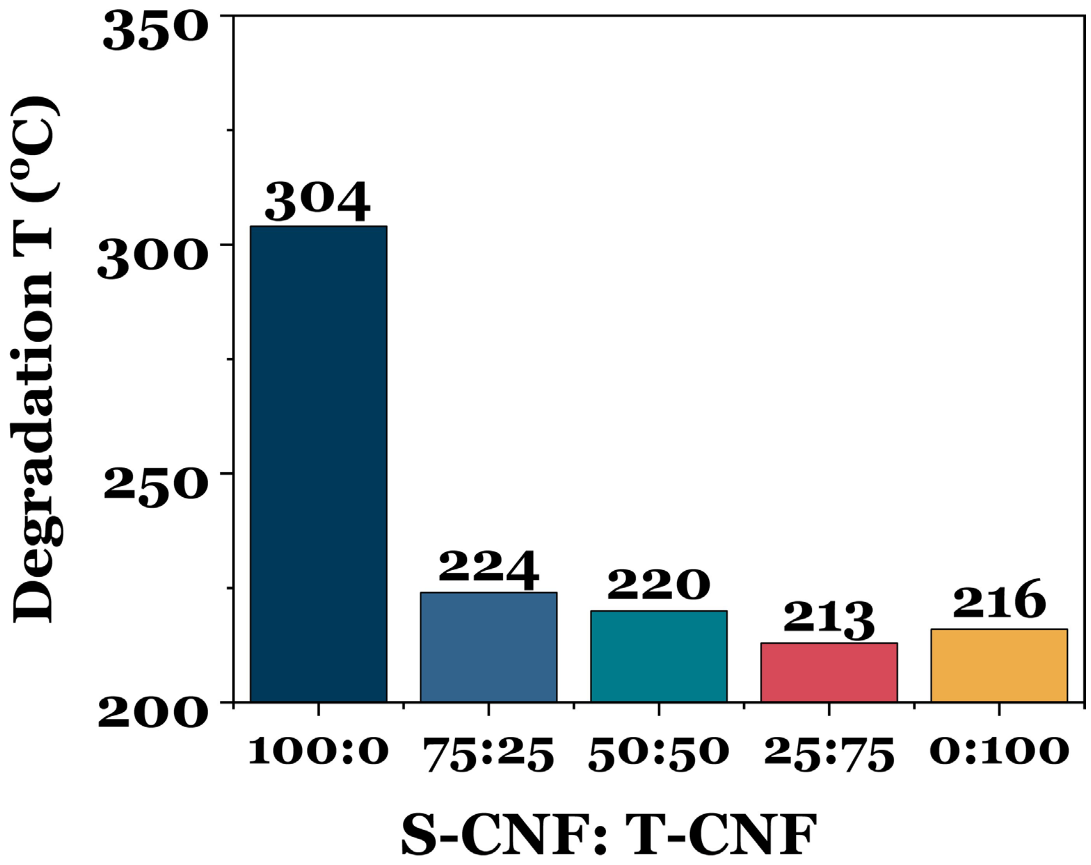


Figure 6. Degradation temperature of the modified CNF membranes.

Results

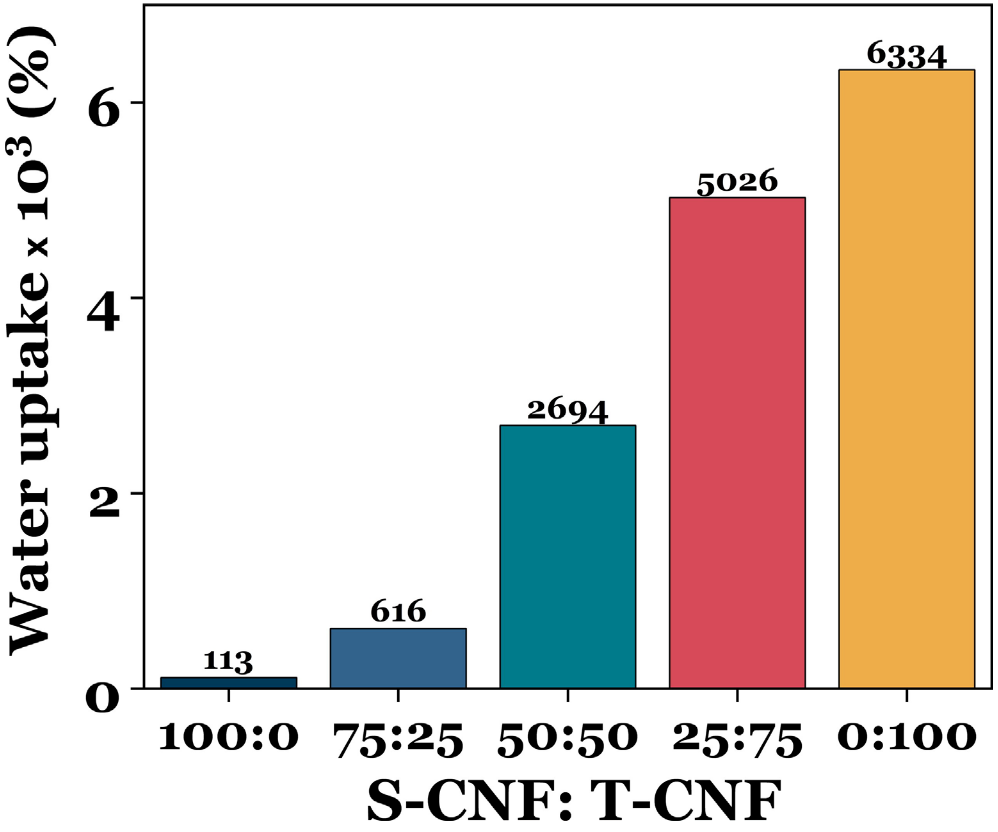


Figure 7. Water uptake of the modified CNF membranes at room temperature

Table 2. IEC (Ion Exchange Capacity) of the modified CNF membranes

Sample	IEC (meq/g)
T-CNF	0.0131
75%T – 25%S	0.0128
50%T – 50%S	0.0117
25%T – 75%S	0.0111
S-CNF	0.0133
Commercial PEM	0.91

T-CNF = TEMPO nanocellulose fibers
S-CNF = Sulfonated nanocellulose fibers
Commercial PEM = Nafion©

Results

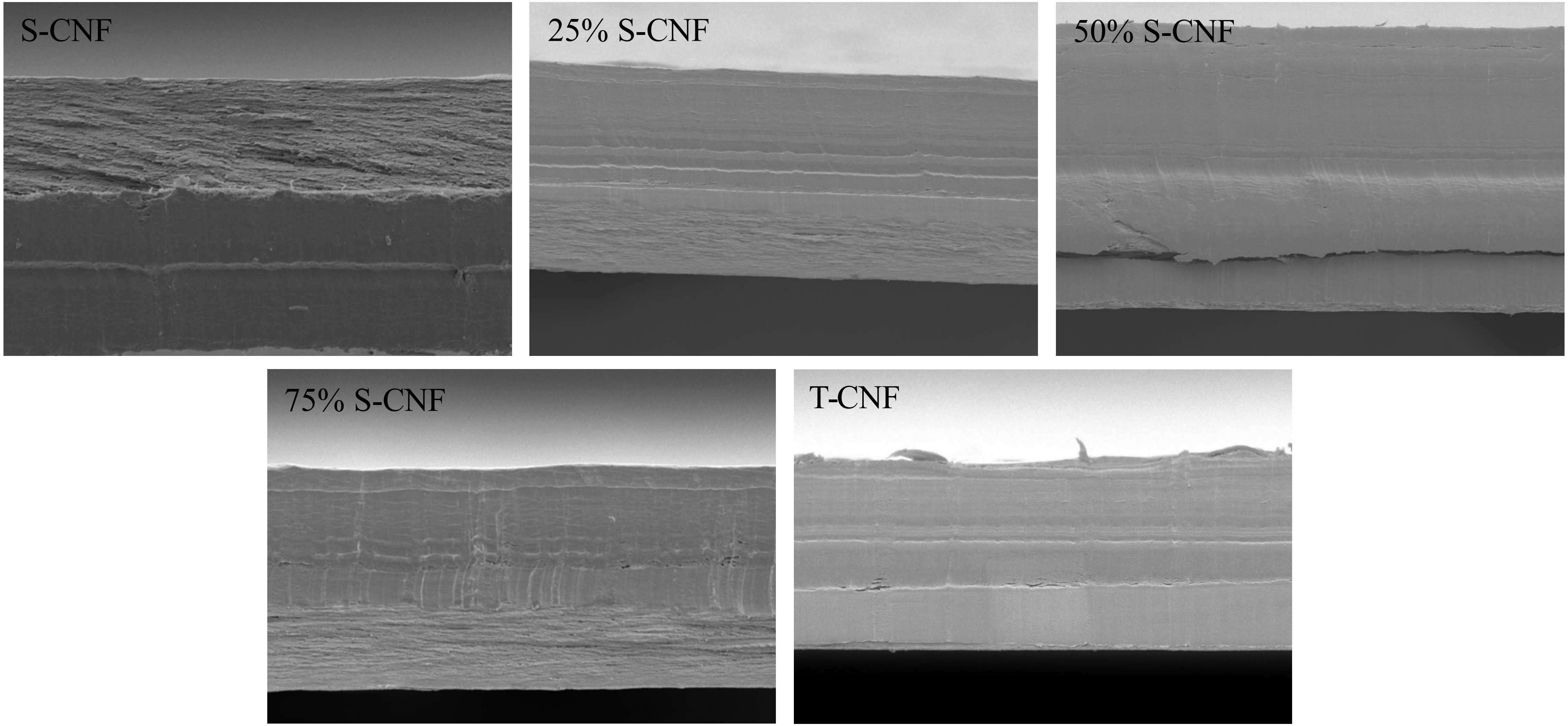


Figure 11. Cross-sectional SEM images of the modified CNF membranes

General results

Table 3. Overall results of the modified CNF membranes

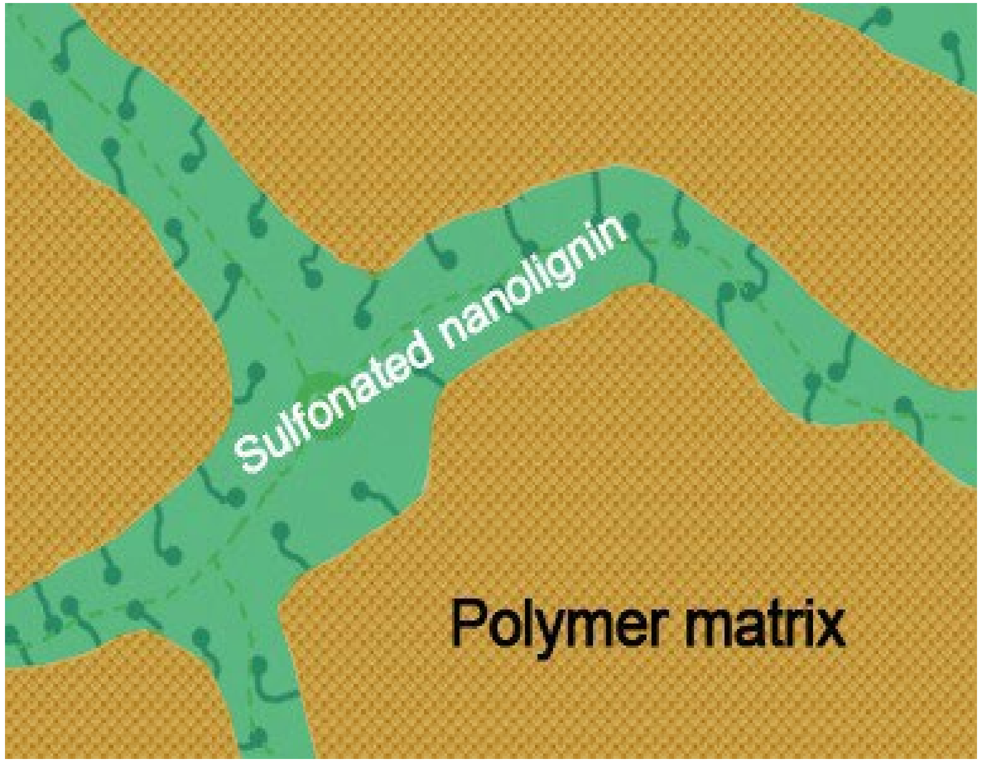
Sample	IEC (meq/g)	Water uptake (%)	Storage modulus (MPa) – 25°C	Deg. Temp. (°C)
T-CNF	0.013126	113	8526	304
75%T – 25%S	0.012839	616	9878	224
50%T – 50%S	0.011789	2694	11034	220
25%T – 75%S	0.011142	5026	7702	213
S-CNF	0.013339	6334	8096	216
Commercial PEM	0.91	50	200	100

T-CNF = TEMPO nanocellulose fibers
S-CNF = Sulfonated nanocellulose fibers
Deg. Temp. = Degradation temperature

1. Stable at PEM fuel cell operating conditions.
2. High degree of swelling
3. IEC of tested samples is far below commercial membranes

2. Study of modified lignin

A novel biobased approach



Our hypothesis:

*Well dispersed **sulfonated lignin nanoparticles** in a polymer solution can serve as **pathways for ion transfer** through the otherwise hydrophobic lignin-based PEM.*

Methodology

Mixture preparation

1. Solution of sulfonated lignin
2. Solution of surfactant

↓

Emulsifier was added to the lignin solution

↓

Ethanol (as an antisolvent) was added (dropwise) to the resulting solution for 1 h to form lignin-sulfonate nanoparticles.

Methodology

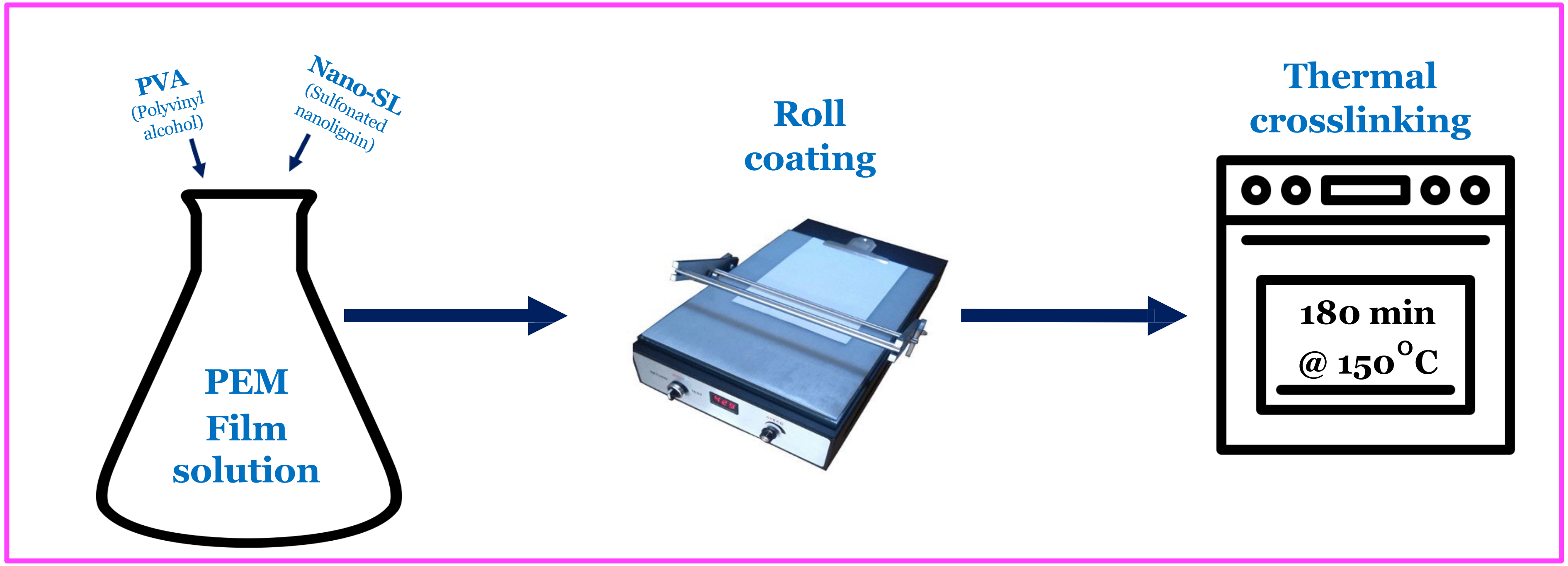
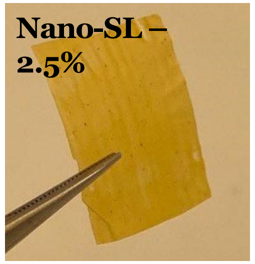
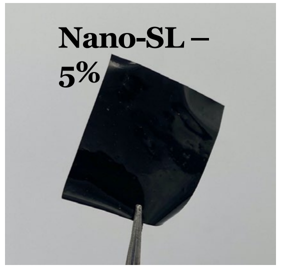


Figure 8. Process to obtain PVA and SL (commercial & nano-SL) membranes.

PVA = Polyvinyl alcohol
SL = Sulfonated lignin
Nano–SL = Sulfonated lignin nanoparticles

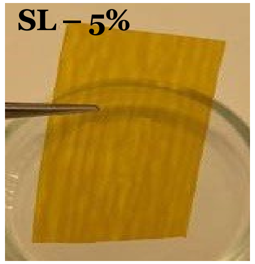


PVA + **Nano-SL - 2.5%**



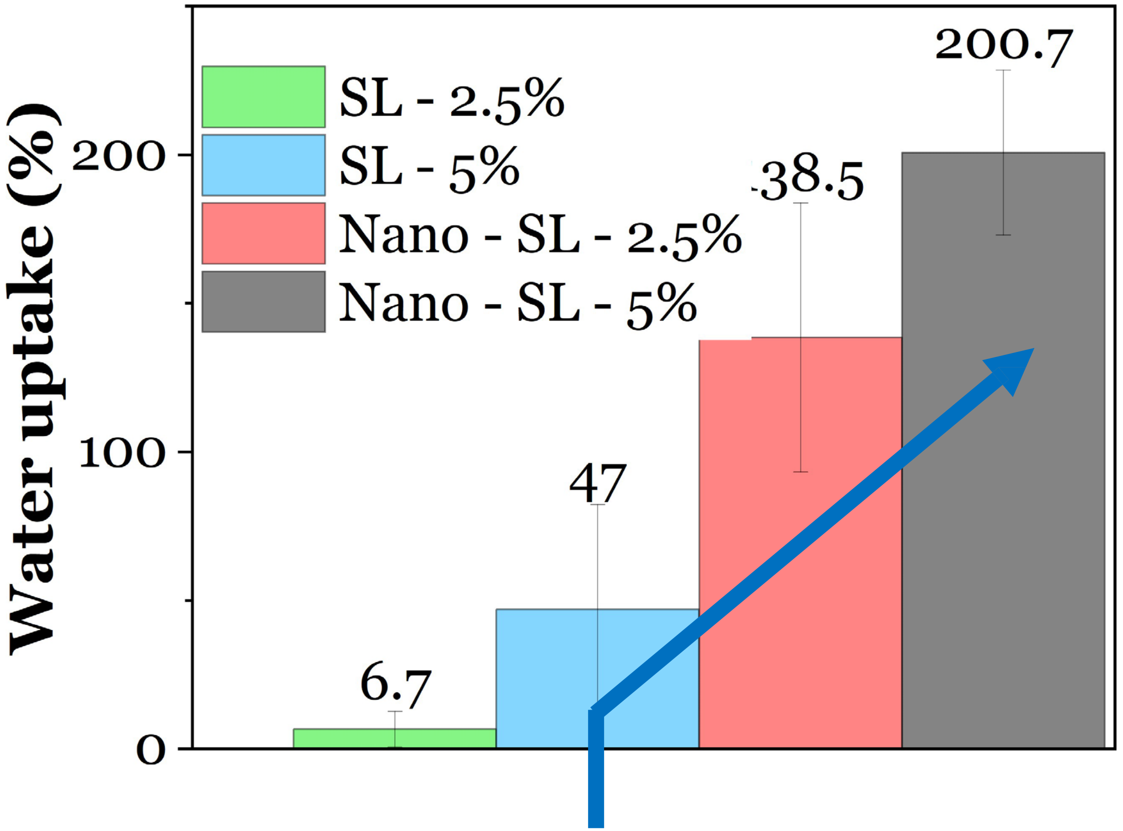
PVA + **Nano-SL - 5%**

PVA + **SL - 2.5%**



PVA + **SL - 5%**

Results



Tunable degree of swelling with Nano-SL concentration

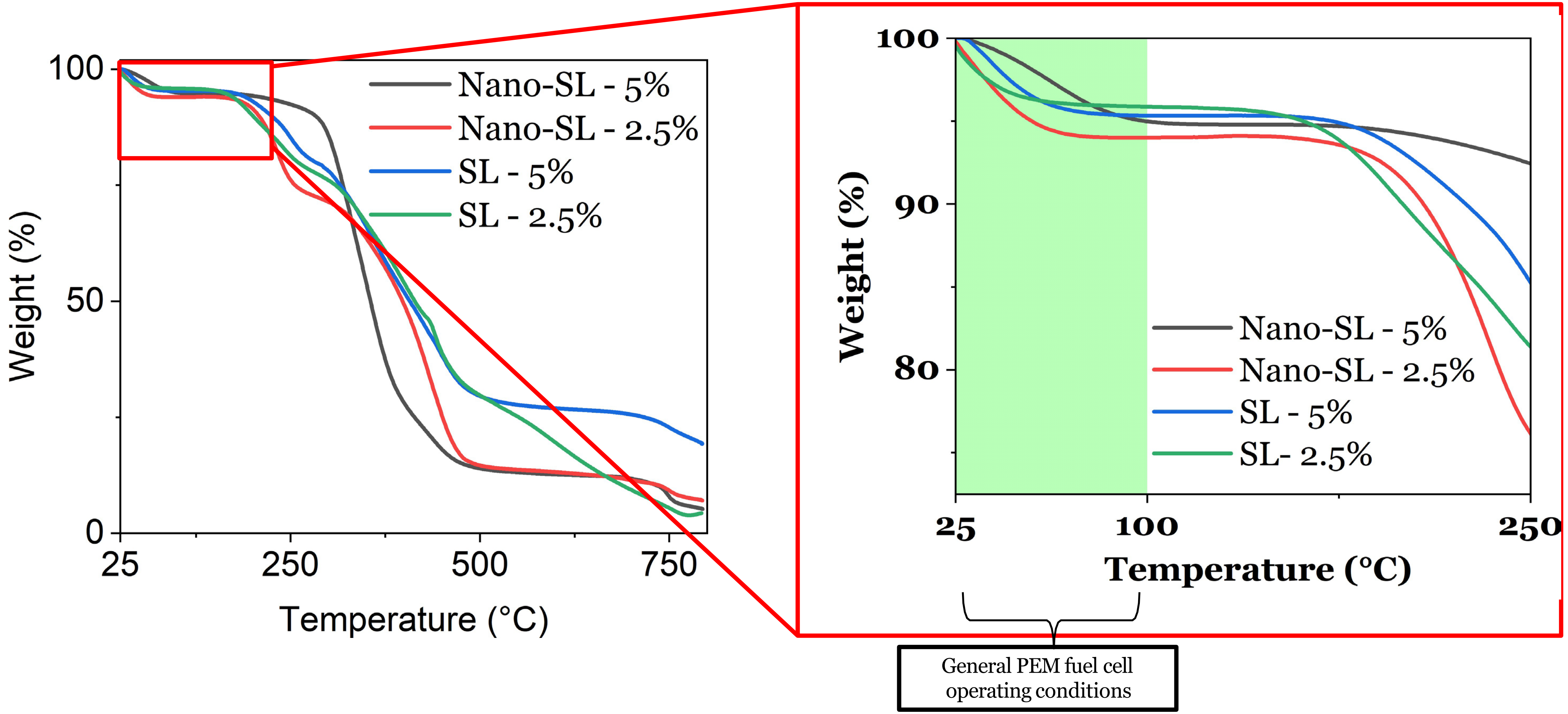
Figure 9. Water uptake of the SL membranes at room temperature

Table 4. Storage modulus of the PVA with SL (commercial & nano) membranes.

Temp.	SL – 2.5%	Nano-SL – 2.5%	Nano-SL – 5%
25°C	711	724	483
80°C	774	709	473

*SL = Sulfonated lignin

Results



**SL = Sulfonated lignin

Figure 10. PVA and LS (commercial LS and nano-LS) membranes.

Results

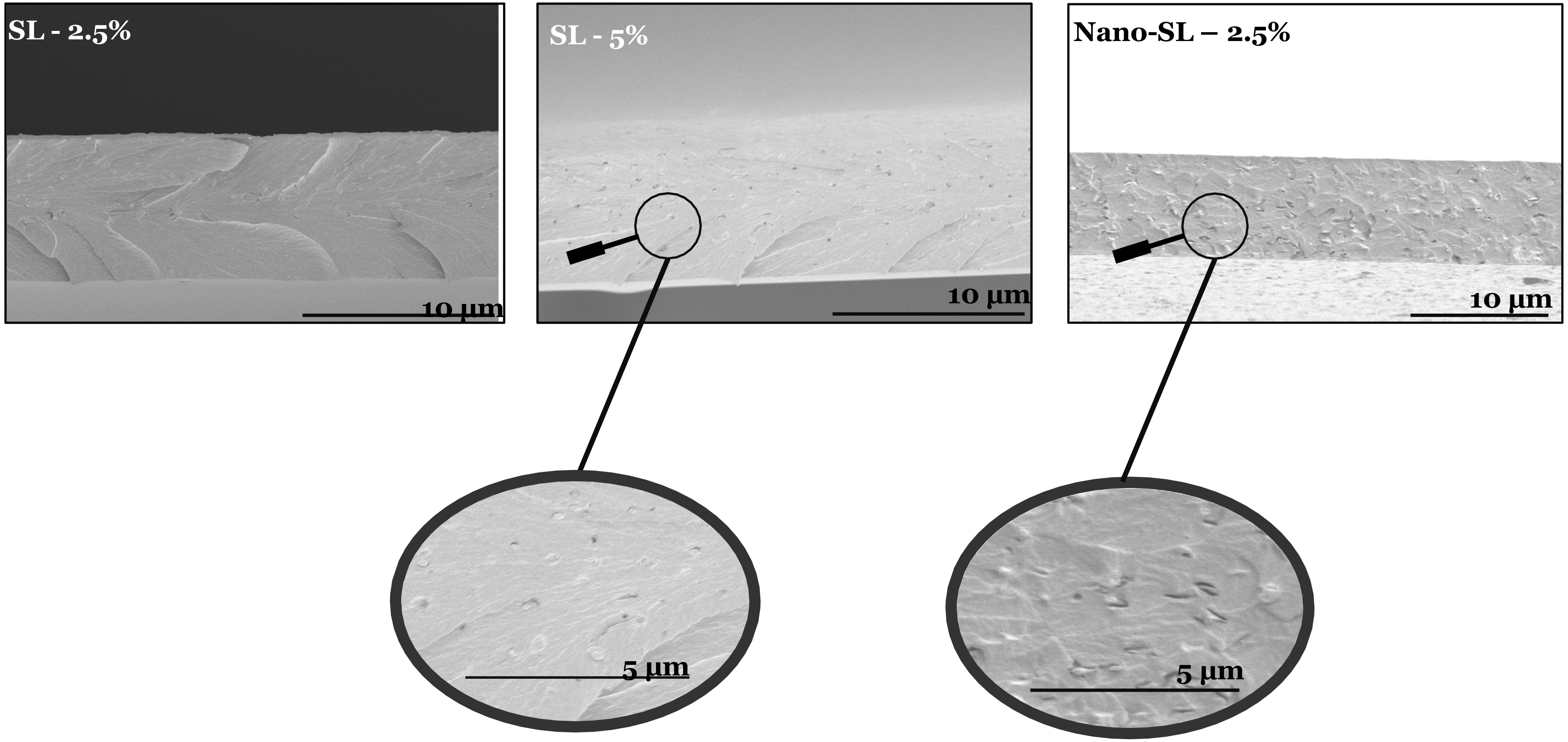


Figure 11. Cross-sectional images the PVA with SL (commercial & nano) membranes

**SL = Sulfonated lignin

Results

Table 5. IEC of PVA and SL (commercial & nano) membranes.

Sample	IEC (meq/g)
Nano-SL (5%)	1.261
Commercial-SL (5%)	0.445
Nano-SL (2.5%)	0.354
Commercial-SL (2.5%)	0.248

*SL = Sulfonated lignin

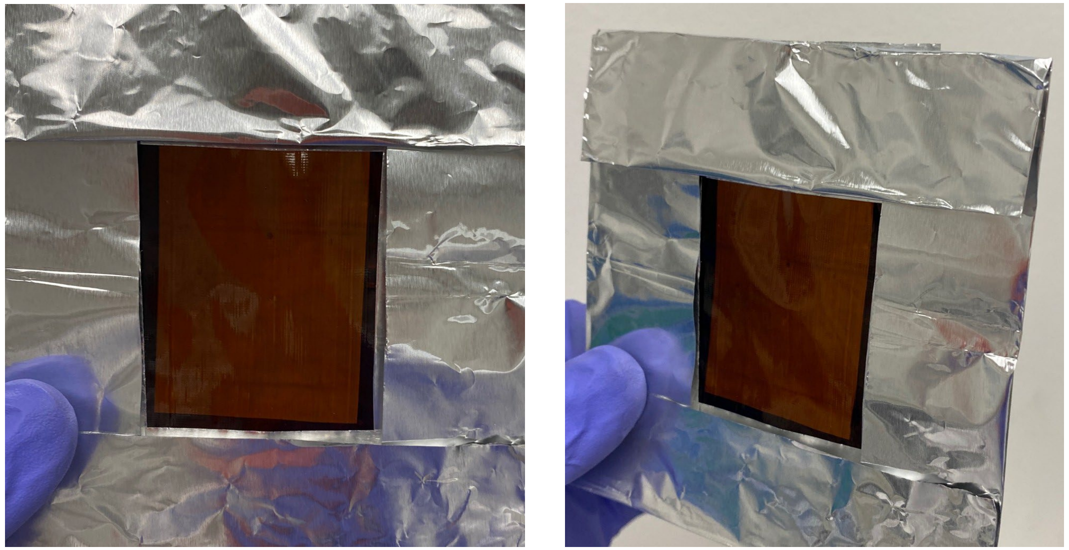


Figure 12. Films of PVA with nano-SL 5%.

General results

Table 6. General results of the PVA and SL (commercial & nano) membranes.

Sample	Nano – SL (2.5%)	Nano – SL (5%)	Commercial PEM
IEC (meq/g)	0.436	1.261	0.91
Storage modulus 25°C (Mpa)	724	483	200
Water uptake (%)	128.5	200.7	50

- The PVA with nano-SL showed comparable results with Nafion.
- Nano-SL is a prospective material to be used in a PEM composition.

Summary

✓ CNF membranes showed high mechanical and thermal stability as well as high degree of hidrophilicity.

✓ Nano-SL membrane showed high mechanical and thermal stability combined with potential eletrochemical application when in added in a matrix of a PEM.

Next steps

- Test nano-SL membrane in a fuel cell station.
- Increase the options of this membrane for other electrochemical application.
- Surface and internal modification of nanolignin.

Acknowledgements

Thank you to the Foster AMG group and the entire BPI!

THE UNIVERSITY OF BRITISH COLUMBIA

Thank you! Any questions?