

Navigating the future of sustainability: A multidimensional patent analysis of lithium-ion battery recycling technologies

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Introduction

Lithium-ion batteries (LIB) play a critical role in enabling the realization of international sustainability goals.

To combat these challenges, massive efforts have been put forward in academia and industry to come up with effective solutions for LIB recycling.

Goal of this study: By using a combined approach of network analysis, clustering, and natural language processing based on patent data, this study aims to **identify collaboration patterns, key knowledge areas, and key competencies of relevant patent assignees in LIB recycling.**



This inevitably leads to mass amounts of end-of-life LIBs whose disposal poses strong environmental, economic, technological and social challenges.



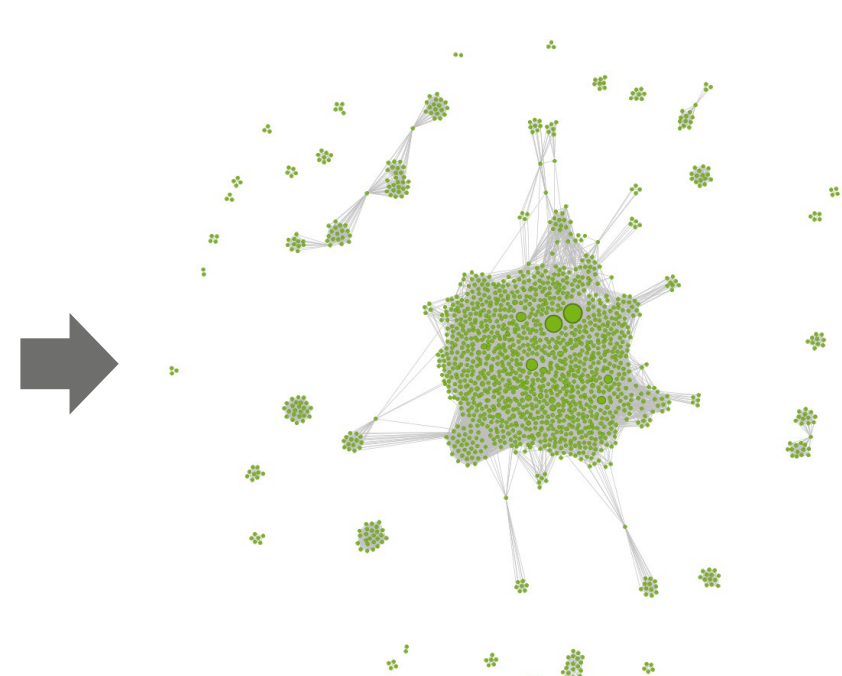
However, very little LIB recycling research has focused on big data patent analysis, a methodology that has gained a lot of traction in other fields.

Methodology

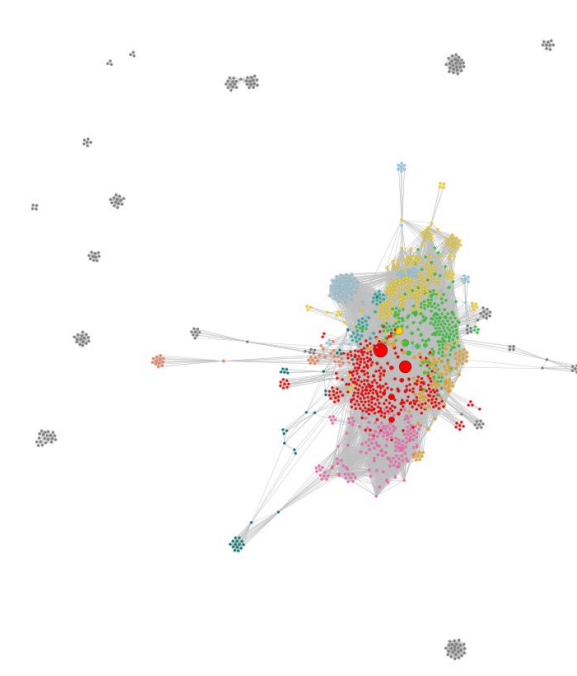
1 Patent extraction

Parameter	Value of parameter
Database	Derwent World Patents Index
Keyword search	(lithium-ion ADJ batter*) AND recycle* → Search includes multiple synonyms
Search in	Title, Abstract, Claims
Time horizon	1990-August 2024
Initial hits	63,109
Hits after clean-up (including „recycl“)	1,233

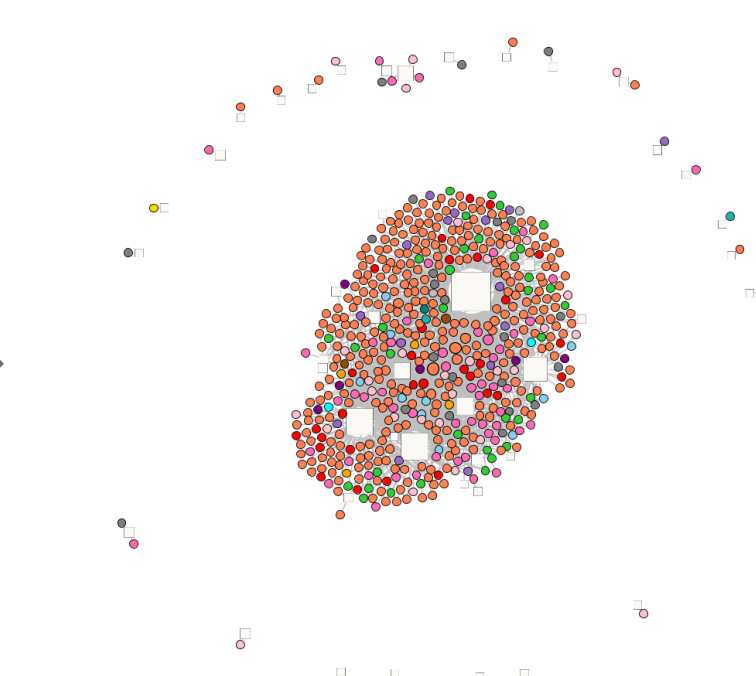
2 Co-occurrence network analysis



3 Leiden clustering & term frequency-inverse document frequency (TF-IDF)



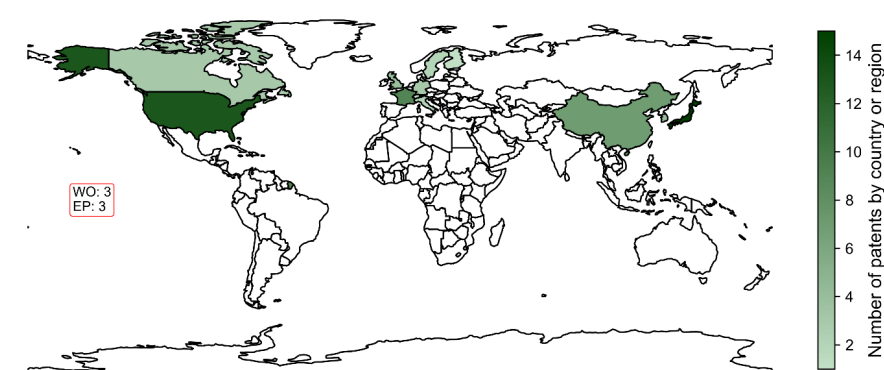
4 Two-mode networks: Assignees' key competencies



Results & Discussion

The number of patents on LIB recycling is growing exponentially.

China has quickly overtaken the US and Japan by a large margin in recent years. Countries in Europe are lagging even further behind in LIB recycling patents.



1990-2004



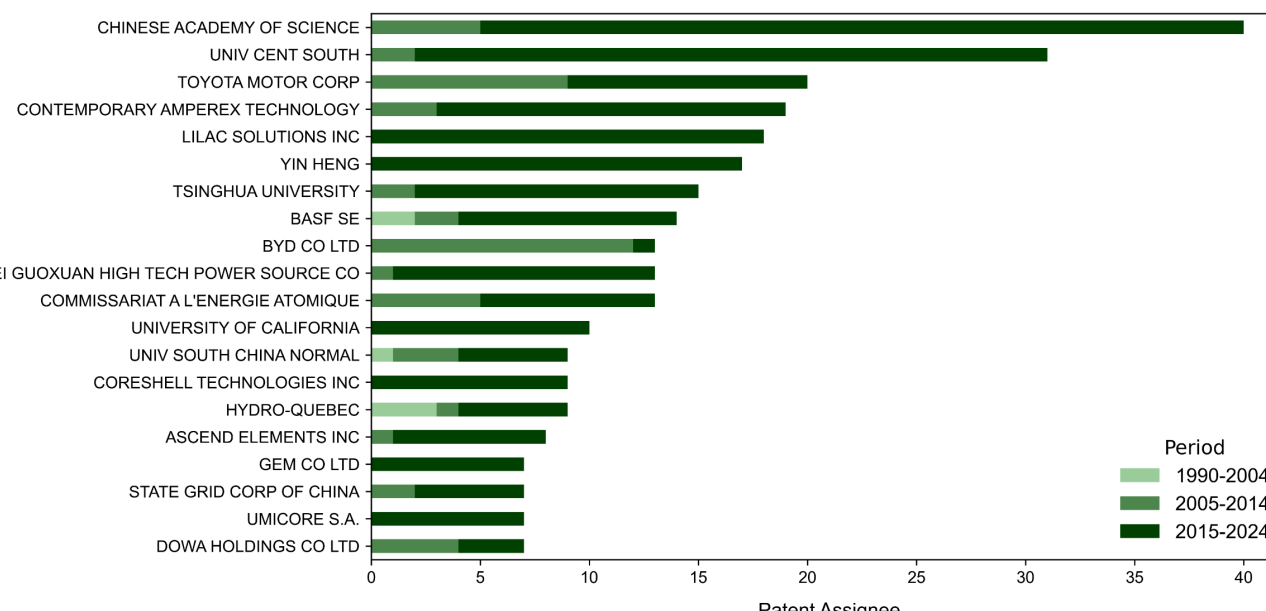
2005-2014



2015-2024

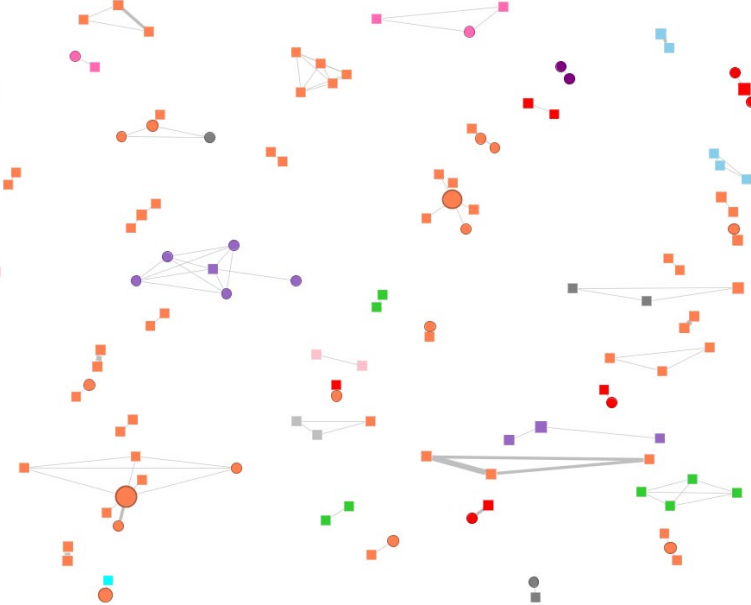


Important patent assignees stem from academia and industry. Large international corporations like Toyota, CATL, BASF, and BYD are already active in this field.



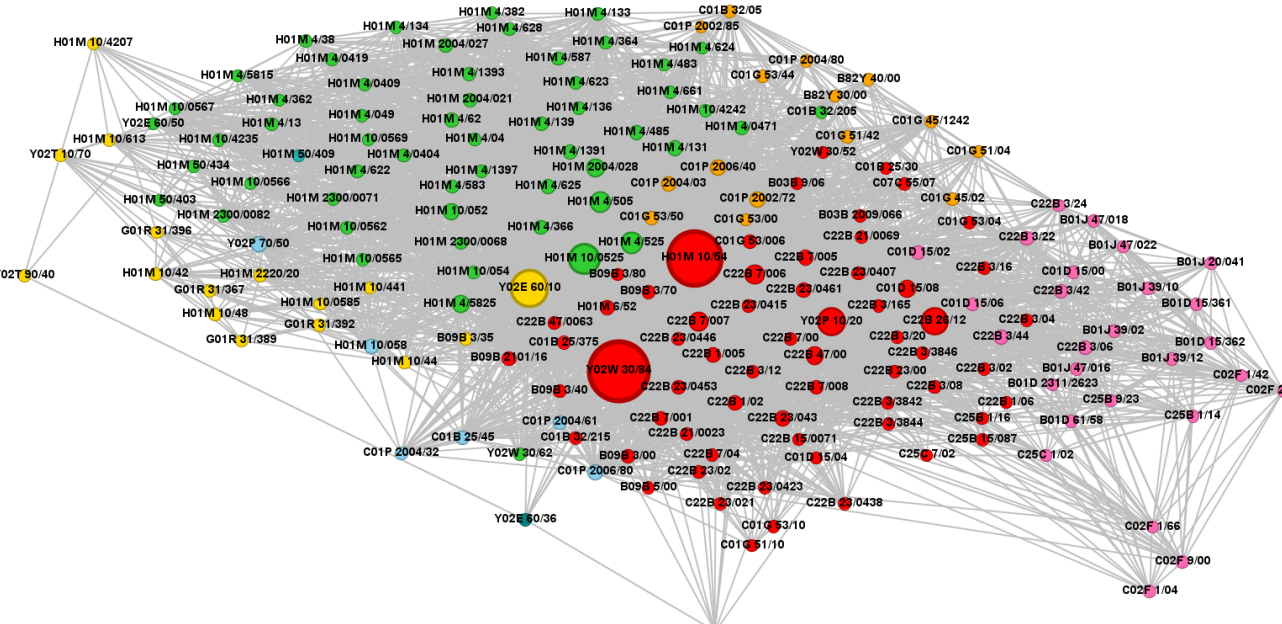
Patent assignee co-occurrence network 2015-2024

- Clear rise in PAs compared to previous years
- Almost no international collaboration
- Huge potential left untapped



Clustered CPC co-occurrence network 2015-2024

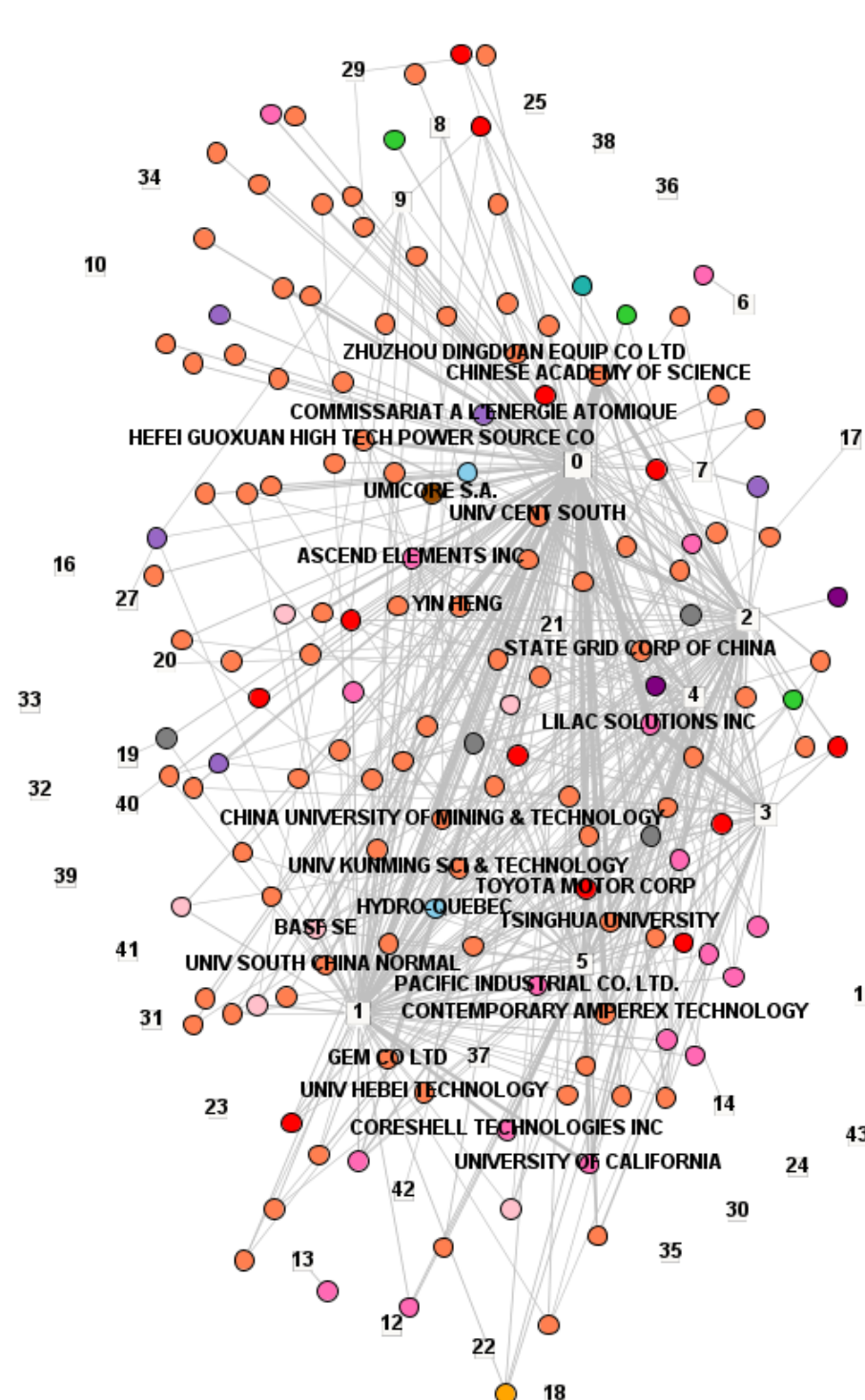
- Leiden clustering clearly identifies 44 different clusters
- Only most important nodes shown here
- Leads to definitive knowledge areas



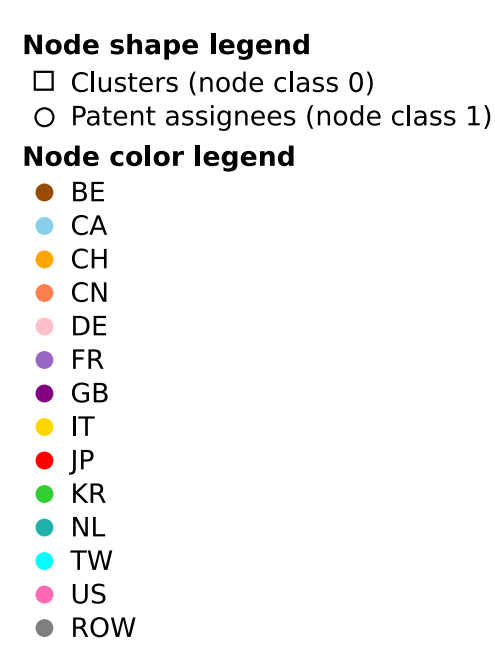
TF-IDF keyword extraction

- Results in ten central descriptive keywords for each cluster (based on CPC class descriptions)
- These were also manually evaluated for the top ten clusters of each period

Two-mode network 2015-2024



- US and China clearly dominant
- Each PA connected to 1 or more knowledge areas (clusters)
- Allows identification of key competence in LIB recycling
- Filtered to include PAs with ≥2 patents



Corresponding descriptions of top knowledge areas

Reflect many components of LIBs and their production

Cluster	Manual description
0	LIB recycling
1	Electrode intercalation
2	Battery testing systems
3	Inorganic solutions, extraction processes
4	Material characterization
5	Micrometer scale production
6	Catalysts
7	Water electrolysis
8	Filtering using separators
9	Filtering using membranes/diaphragms

Conclusion

1. China is once again flooding a research field with patents.
2. Europe has to act fast to not be left behind.
3. Research on LIB recycling is still heavily carried out by universities.
4. International collaboration potential is largely untapped.

Outlook

- Patent analyses in LIB recycling remain under-utilized → expand efforts
- Use more sophisticated natural language processing for more accurate insights
- Additionally look at patent quality instead of quantity

Contact

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Let's connect



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