Supporting information: Uncovering collaboration and knowledge areas in lithium-ion battery recycling

Simon Schlehuber[1,*], André Hemmelder[1], Stephan von Delft[1,2]

[1] Institute of Business Administration at the Department of Chemistry and Pharmacy, University of Münster, Leonardo Campus 1, 48149 Münster, Germany

[2] University of Glasgow, Adam Smith Business School, Glasgow, G12 8QQ, United Kingdom

*Corresponding author. E-mail address: simon.schlehuber@uni-muenster.de

S1 Patent extraction and filtering methodology

As described in Section 3.1, the initial patent extraction was performed using a keyword search. This search targeted the “CTB” field (revised title, abstract, and claims) in the Derwent World Patents Index. The keywords were derived from a bibliometric analysis of recycling methods for spent LIBs[1], with manual standardisation of battery-related search terms to ensure comprehensive retrieval and address inconsistencies (e.g. consistently pairing “li-ion” and “lithium-ion”). To ensure reasonable initial capture, the list of search terms (shown in Table S1) was intentionally kept broad. Wildcard truncation (“*”) captures alternate word forms. Logical operators, Boolean logic, and field restrictions used for the Derwent search exactly match the query structure shown in Table S1. The search was not restricted by language, as Derwent provides reliable English translations, nor by specific CPC codes to preserve downstream analysis. All patents from January 1, 1990 (AD>=(19900101)) onward were included.

Table S1: Complete list of search terms used in this study. The search yielded **63,109** patent families.

CTB=((li-ion ADJ batter*) OR (lithium-ion ADJ cell*) OR (li-ion ADJ cell*) OR (lithium-ion ADJ power ADJ batter*) OR (li-ion ADJ power ADJ batter*) OR (lithium-ion ADJ secondary ADJ batter*) OR (li-ion ADJ secondary ADJ batter*) OR LIB OR (ternary ADJ batter*) OR (lithium-ion ADJ rechargeable ADJ batter*) OR (li-ion ADJ rechargeable ADJ batter*) OR LiFePO4 OR LiCoO2 OR NMC OR LiMn2O4 OR (li-ion ADJ accumulator*) OR (lithium-ion ADJ accumulator*)) **AND CTB=**(recycl* OR circular* OR (circular ADJ economy) OR recover* OR regenerat* OR reclaim* OR reus* OR separat* OR synthesiz* OR remanufactur* OR reproduc* OR repair* OR renovat* OR remediat* OR reviv* OR determinat* OR purify* OR detect* OR measur* OR characteriz* OR refunction* OR regain* OR repurpos* OR hydrothermal OR hydrometallurg* OR leach* OR bioleach* OR prepar* OR fabricat* OR produc* OR extract OR precipitat* OR co-precipitat* OR dissolv* OR electrolysis OR electroosmosis OR electrodialysis OR electrodeposit OR electrowinning OR pyrometallurg* OR roast* OR calcinat* OR bak* OR flotation OR mechanochemical OR pyrolysis OR sinter* OR heat-treat* OR disassembl* OR crush* OR pretreat* OR scrap* OR discharg* OR shred* OR fragment* OR comminut* OR smash) **AND AD>=**(19900101)

In a subsequent step, the scope was narrowed in the Python script to include only those patents containing the term “recycl” in the abstract, title, or claims. This captured all derivatives due to Python substring matching. Further data pre-processing steps, including other filtering procedures, may be found in the accompanying code on GitHub, where patents were deduplicated based on application number, entries with missing core data fields (priority date, priority region, CPC code, assignee) were excluded, and fields were normalised to lowercase. Quantitatively, our initial query

yielded 63,109 patent families, which were reduced to 1,233 patent families after applying the described clean-up and “recycl” filtering as the final analytical dataset.

S2. Example networks

As referenced in Chapter 3.2.1., Figure S1 features two sample networks. Panel a) shows a simple weighted one-mode network containing a single node class, while panel b) displays a weighted two-mode network with two different node classes. As is a characteristic of this type of network, nodes of the same class are never directly connected to each other. Instead, nodes can only be interconnected to nodes of the opposite class.

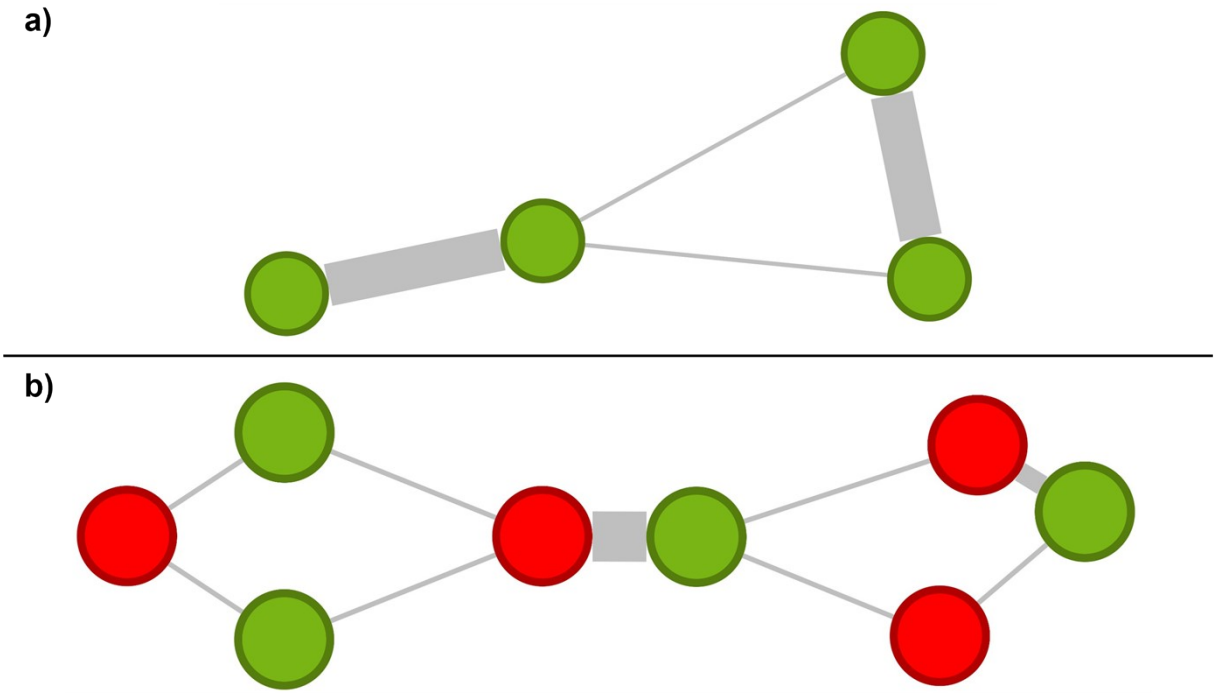

Figure S1: a) Example of a weighted one-mode network. b) Example of a weighted two-mode network

S3. Corresponding descriptions of the top 20 most frequent CPC-classes in the patent dataset

Table S2 features the full descriptions of the top 20 most frequent Cooperative Patent Classification (CPC) classes in the patent dataset as found in Espacenet[2].

Table S2: Overview of the top 20 most frequent CPC classes in the patent dataset. Words in "[ ]" are added based on the descriptions of higher corresponding CPC codes to increase clarity.

CPC-Symbol	**CPC-Description**
Y02W 30/84	Recycling of batteries or fuel cells
H01M 10/54	Reclaiming serviceable parts of waste accumulators
Y02E 60/10	Energy storage using batteries
H01M 10/0525	Rocking-chair batteries, i.e. batteries with lithium insertion or intercalation in both electrodes; Lithium-ion batteries
Y02P 10/20	Recycling
C22B 26/12	Obtaining lithium
H01M 4/525	of mixed oxides or hydroxides containing iron, cobalt or nickel for inserting or intercalating light metals, e.g. LiNiO2, LiCoO2 or LiCoOxFy
H01M 4/505	of mixed oxides or hydroxides containing manganese for inserting or intercalating light metals, e.g. LiMn2O4 or LiMn2OxFy
C22B 7/006	Wet processes
C22B 7/007	by acid leaching
H01M 2004/028	Positive electrodes
H01M 10/052	Li-accumulators
H01M 4/5825	Oxygenated metallic salts or polyanionic structures, e.g. borates, phosphates, silicates, olivines
C22B 47/00	Obtaining manganese
Y02P 70/50	Manufacturing or production processes characterised by the final manufactured product
C01D 15/08	Carbonates; Bicarbonates [Lithium compounds]
C01P 2006/40	Electric properties [of inorganic compounds]
C01P 2002/72	[crystal structural characteristics] by d-values or two theta-values, e.g. as X-ray diagram

H01M 4/131	Electrodes based on mixed oxides or hydroxides, or on mixtures of oxides or hydroxides, e.g. LiCoOx
C01P 2006/80	Compositional purity [of inorganic compounds]

S4 Term frequency-inverse document frequency (TF-IDF) hyperparameters

The TF-IDF analysis was performed using the *TfidfVectorizer* module from the *scikit-learn* (version 1.5.0) library[3]. All hyperparameters were set to default values, as summarised in Table S3. The choice to use defaults reflects a focus on established and easily reproducible settings. The stop_words parameter was set to “None” since stopwords were already removed during preprocessing. The key hyperparameters, their default values, and relevant implications for the analysis are detailed below.

Table S3: Overview and implications of key TF-IDF hyperparameters used in this study.

Parameter	Default value	Description	Implications
ngram_range	(1, 1)	Only single words (unigrams) are considered as features	Key phrases (e.g. “lithium ion”) not detected as a unit
min_df	1	Terms must appear in ≥1 document to be included	All non-stopword terms included, even very rare ones
max_df	1.0	Terms may appear in all documents	Terms common across all clusters are not filtered out
max_features	None	No upper limit on the number of features	Complete vocabulary included; most relevant terms extracted
stop_words	None	No stopwords removed by vectorizer—filtered during preprocessing with *nltk*	Allows full control over standard and domain stopwords
token_pattern	\b\w\w+\b	Tokens are ≥2 alphanumeric chars	Single-letter tokens are ignored
norm	l2	Each cluster’s TF-IDF vector is scaled to unit Euclidean norm	Ensures keyword scores are comparable within clusters
use_idf	True	Weights penalise terms common across the corpus	Reduces influence of highly generic terms

smooth_idf	True	Adds 1 to document frequencies for IDF calculation	Avoids division by zero and stabilises weights
sublinear_tf	False	Raw term frequencies used; no logarithmic scaling	Terms are counted linearly with their frequency
lowercase	True	Converts all text to lowercase	Is redundant with preprocessing, but has no drawbacks for results
binary	False	If True, all nonzero term counts are set to 1 (only presence or absence is considered); frequency is ignored.	Term frequency is considered, so more frequent words receive higher TF-IDF scores.

S5. Supplementary patent assignee co-occurrence networks

To complement Figure 7 of the manuscript, this section depicts the full patent assignee co-occurrence network labelled completely (Figure S2) and the corresponding unlabelled network (Figure S3).

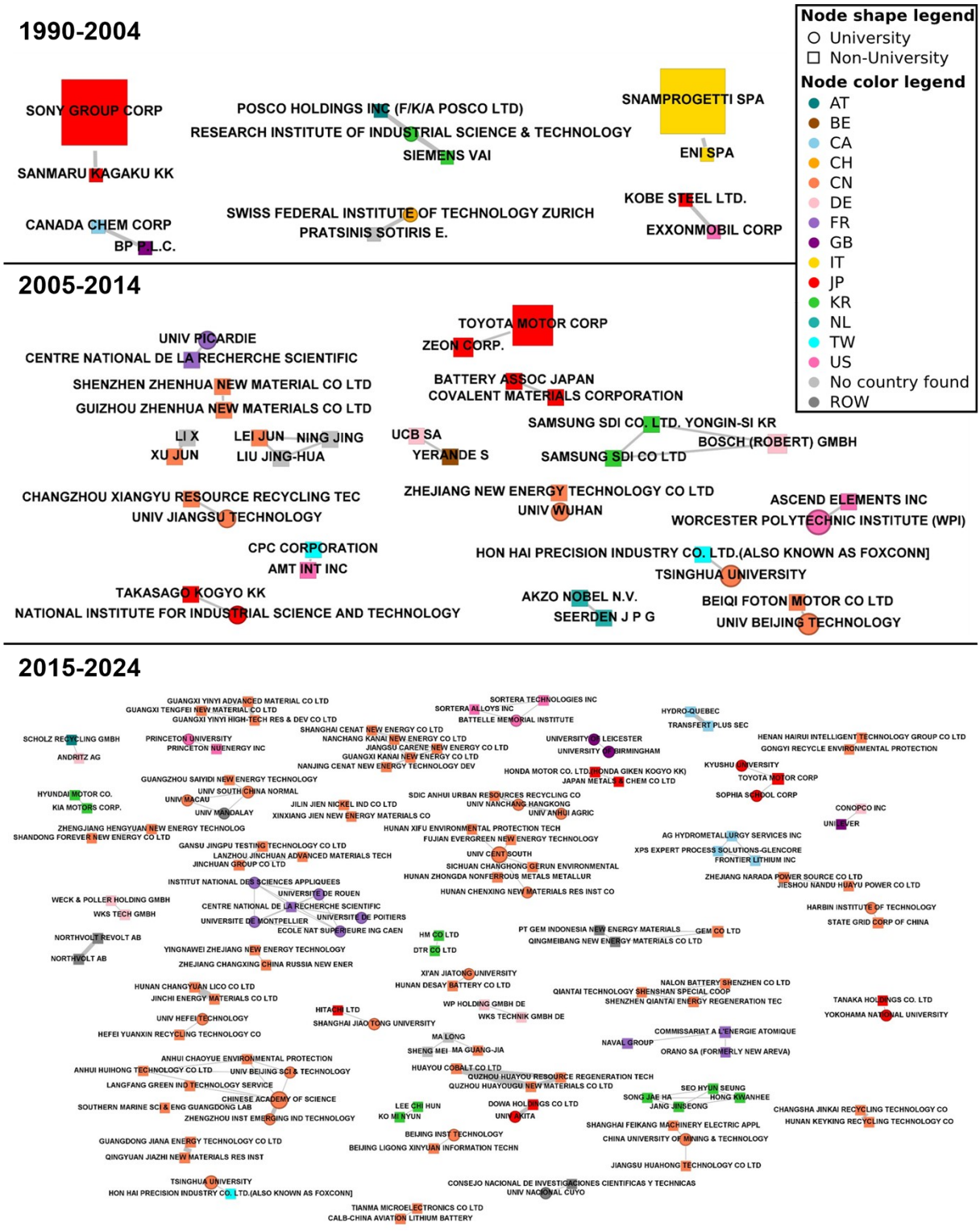

Figure S2: Overview of full labelled patent assignee co-occurrence networks over three periods.

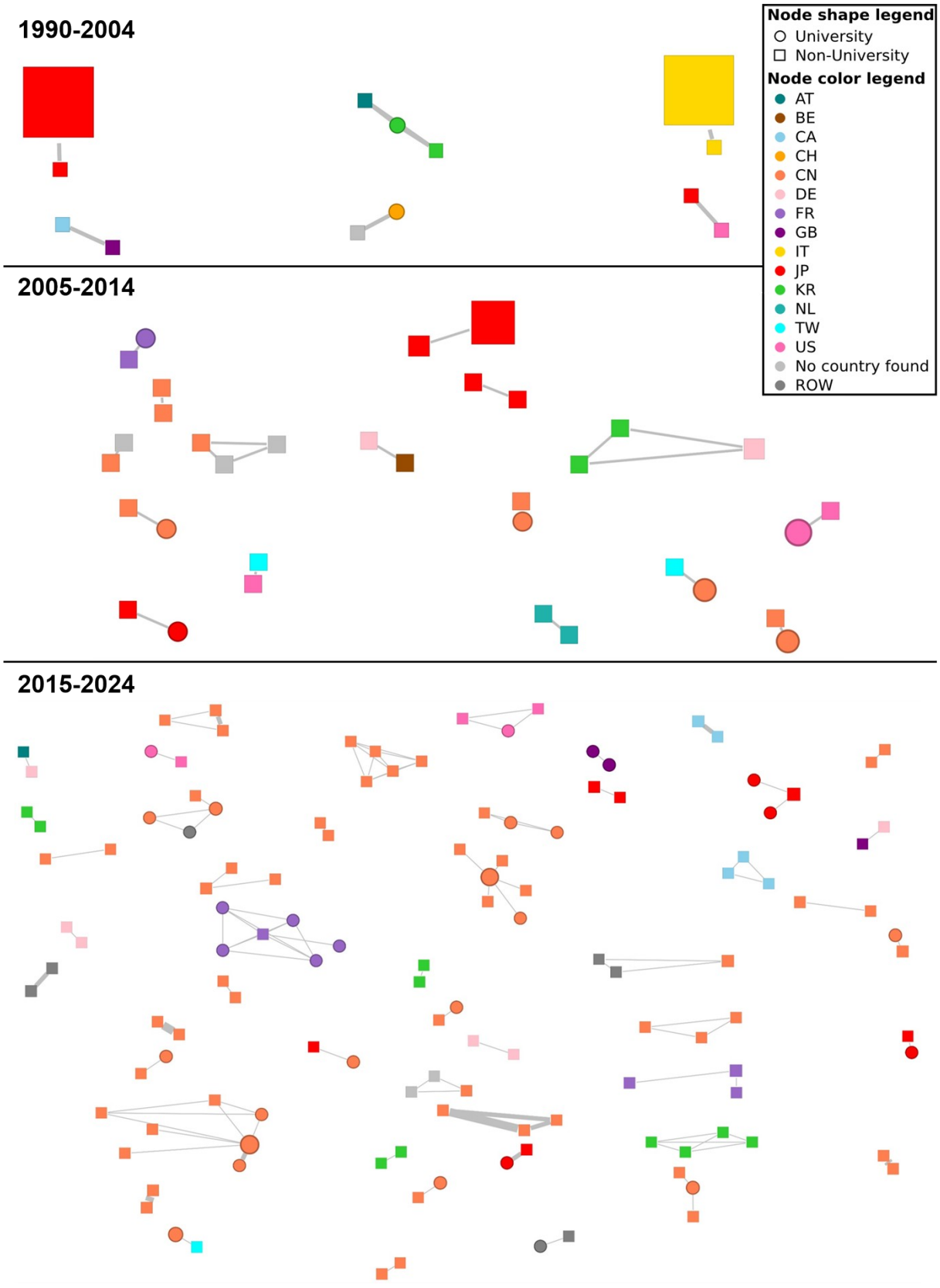

Figure S3: Overview of full unlabelled patent assignee co-occurrence networks over three periods.

S6. Supplementary CPC co-occurrence and clustered CPC co-occurrence networks

To complement Figure 8 of the manuscript, this section first presents the fully labelled CPC co-occurrence networks filtered to include only nodes with a weight of 5 or more (Figure S4), followed by the completely unfiltered and unlabelled networks used in the CPC co-occurrence analysis (Figure S5).

To complement Figure 9, it then features the fully labelled clustered CPC co-occurrence networks filtered to nodes with a weight of 5 or more (Figure S6), and finally, the completely unfiltered and unlabelled clustered CPC co-occurrence networks (Figure S7).

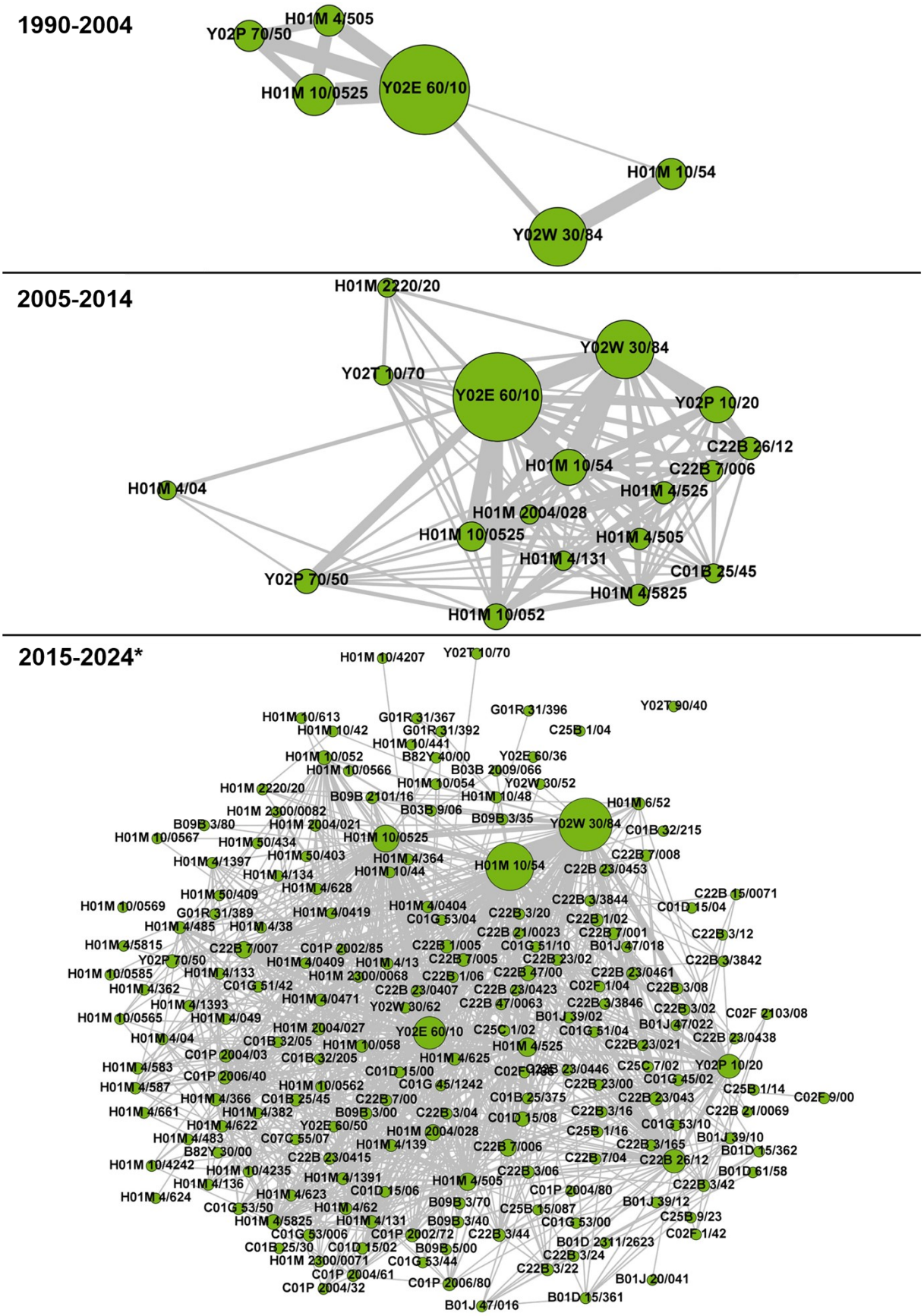

Figure S4: Overview of CPC co-occurrence networks for three periods. Only nodes with weight ≥5 are shown. *To increase readability, edges with weights below five are filtered out.

Figure S5: Overview of full CPC co-occurrence networks over three periods.

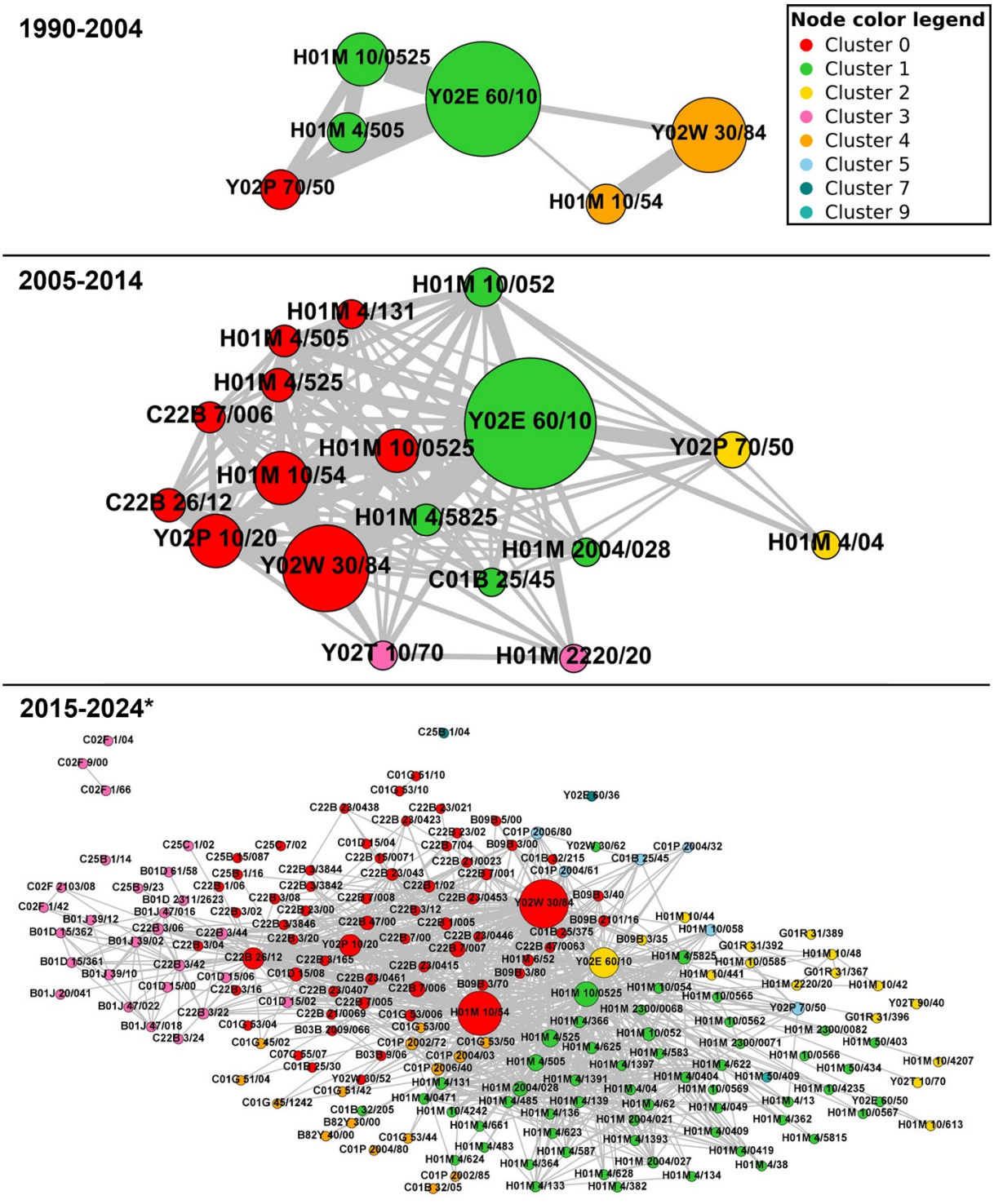

Figure S6: Overview of clustered CPC co-occurrence networks for three periods. Only nodes with weight ≥5 are shown. Only the 10 nodes with the highest weights are labelled. *To increase readability, edges with weights below five are filtered out.

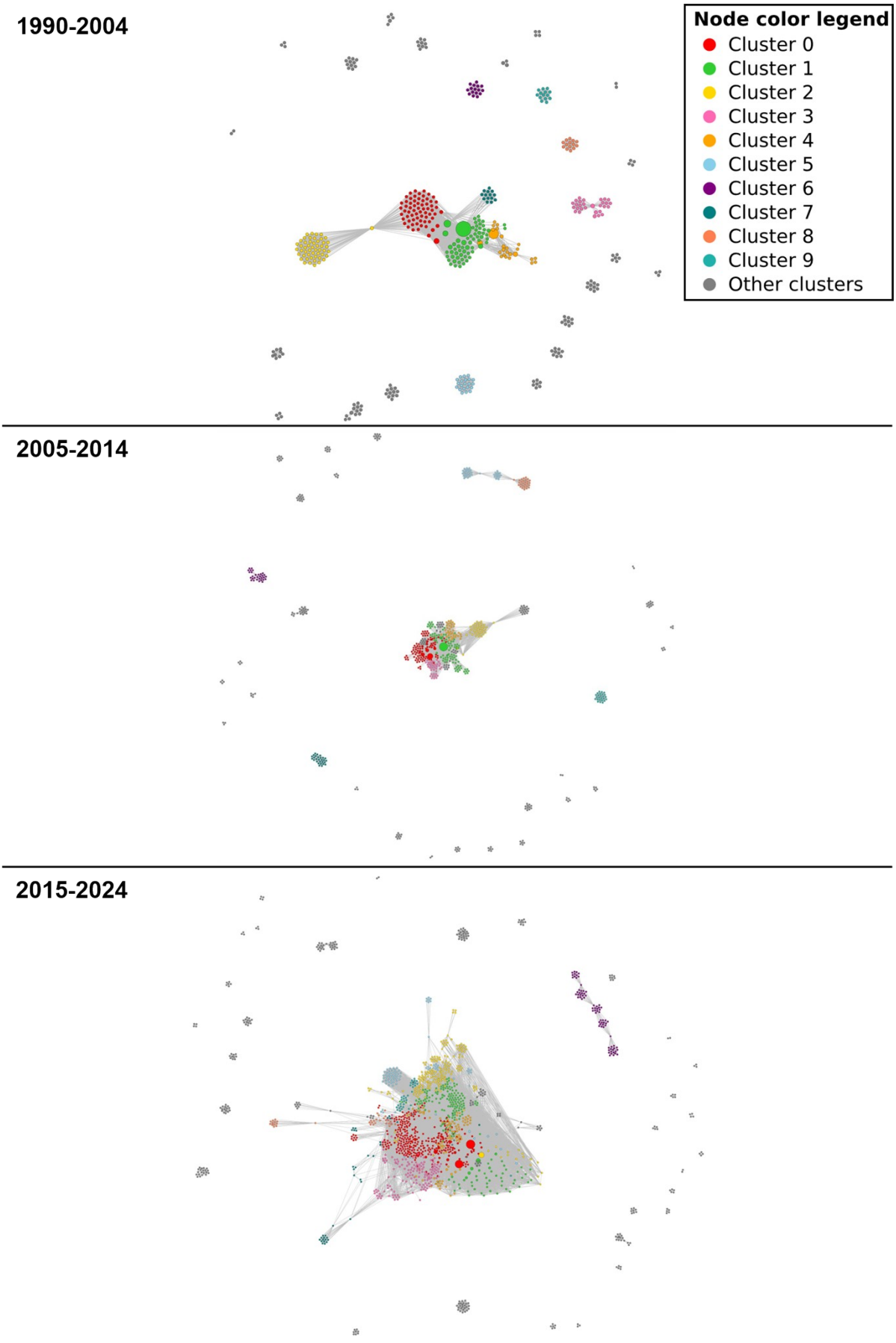

Figure S7: Overview of full clustered CPC co-occurrence networks over three periods.

S7. Full lists of keywords describing the clusters

Tables S4 to S6 present the top ten keywords for each cluster across all periods. These keywords were extracted using the TF-IDF methodology. In some clusters, fewer than ten keywords were identified because certain clusters are so small that their corresponding CPC class descriptions contain fewer than ten words. Consequently, TF-IDF analysis was not essential for these smallest and least significant clusters.

Table S4: Overview of the top ten extracted keywords for each cluster from 1990 to 2004.

Cluster-ID	Central Keywords
0	['oxides', 'thereof', 'salts', 'oxide', 'final', 'manufactured', 'nanometer', 'manufacturing', 'production', 'product']
1	['batteries', 'energy', 'storage', 'oxides', 'electrodes', 'hydroxides', 'mixed', 'inserting', 'intercalating', 'intercalation']
2	['catalysts', 'plates', 'catalytically', 'step', 'product', 'fuel', 'gases', 'feed', 'active', 'cells']
3	['ligands', 'groups', 'containing', 'carbon', 'separation', 'hydroxy', 'including', 'bonds', 'comprising', 'catalysts']
4	['recycling', 'cells', 'batteries', 'fuel', 'accumulators', 'reclaiming', 'serviceable', 'waste', 'parts', 'processes']
5	['joined', 'joining', 'several', 'parts', 'form', 'articles', 'least', 'ir', 'reciprocating', 'welding']
6	['work', 'film', 'separating', 'apparatus', 'plastics', 'single', 'subclass', 'part', 'recycling', 'means']
7	['manufacture', 'processes', 'inorganic', 'diluents', 'nanobatteries', 'electrolytes', 'impregnation', 'solution', 'paste', 'electrode']
8	['meth', 'acrylate', 'containing', 'polyethylene', 'glycol', 'moiety', 'alcohol', 'treatment', 'methoxy', 'acrylic']
9	['filter', 'ultraviolet', 'filtrate', 'measuring', 'flow', 'devices', 'membrane', 'filters', 'rate', 'irradiation']
10	['groups', 'hydroxy', 'primary', 'containing', 'hydroxyl', 'ether', 'bound', 'group', 'carbon', 'without']
11	['carboxylic', 'acids', 'acid', 'halides', 'isomers', 'conversion', 'salts', 'part', 'anhydrides', 'derivatives']
12	['compositions', 'derivatives', 'compounds', 'epoxy', 'polyesters', 'resins', 'polymers', 'according', 'chemical', 'thereof']

13	['means', 'receptacle', 'additional', 'raising', 'vertical', 'like', 'assisting', 'tipping', 'keeping', 'lengthwise']
14	['polymers', 'compounds', 'dicarboxylic', 'dihydroxy', 'one', 'compositions', 'macromolecular', 'aromatic', 'unsaturated', 'containing']
15	['hydrocarbons', 'containing', 'ring', 'alumina', 'naphthalene', 'preparation', 'none', 'hydrocarbon', 'propyltoluene', 'vinyltoluene']
16	['unspecified', 'rubbers', 'characterised', 'moulding', 'undesirable', 'residual', 'monomers', 'degassing', 'centrifugal', 'fluidised']
17	['one', 'radical', 'aliphatic', 'double', 'homopolymers', 'copolymers', 'bond', 'carboxyl', 'unsaturated', 'ester']
18	['discovery', 'potential', 'user', 'area', 'limitation', 'expansion', 'scope', 'consultation', 'announcement', 'among']
19	['atms', 'operations', 'within', 'handling', 'housing', 'dispensing', 'accessories', 'automatic', 'teller', 'machines']
20	['resulting', 'excipient', 'pure', 'drug', 'agglomerate', 'optionally', 'containing', 'antivirals', 'drugs', 'nutrients']
21	['comprising', 'electrodialysis', 'sorbents', 'binder', 'aggregated', 'agglomerated', 'granulated', 'products', 'forming', 'provided']
22	['ptfe', 'polytetrafluorethylene', 'helical', 'teeth', 'screw', 'carter', 'arrangements', 'admission', 'discharge', 'working']
23	['flow', 'outlet', 'liquid', 'gas', 'intersecting', 'jets', 'deflecting', 'central', 'towards', 'peripheral']
24	['dispersed', 'adsorbents', 'absorbents', 'selection', 'liquid', 'materials', 'removing', 'organic', 'compounds']
25	['quinone', 'imines', 'imino', 'unsaturated', 'ring', 'groups', 'compounds', 'containing']
26	['air', 'sterile', 'surgical', 'table', 'application', 'units', 'peltier', 'effect', 'clean', 'stations']
27	['pressure', 'cookers', 'fryers', 'steam', 'water']
28	['esters', 'amino', 'hydrolysis', 'formation', 'halides', 'amides', 'carboxyl', 'purification', 'separation', 'reactions']

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115 Table S5: Overview of the top ten extracted keywords for each cluster from 2005 to 2014.

Cluster-ID	Central Keywords
0	['batteries', 'recycling', 'fuel', 'cells', 'reclaiming', 'serviceable', 'waste', 'lithium', 'hydroxides', 'parts']
1	['storage', 'batteries', 'energy', 'active', 'phosphates', 'silicates', 'polyanionic', 'borates', 'oxygenated', 'metallic']
2	['final', 'manufactured', 'product', 'manufacturing', 'processes', 'characterised', 'production', 'manufacture', 'electrodes', 'form']
3	['batteries', 'battery', 'controller', 'systems', 'data', 'state', 'electromobility', 'transfer', 'several', 'sequentially']
4	['alloys', 'si', 'based', 'electrodes', 'metals', 'silicon', 'solutes', 'making', 'battery', 'electrolyte']
5	['gasification', 'removing', 'carbon', 'water', 'recovery', 'cogeneration', 'pressure', 'dioxide', 'distributors', 'electrolysis']
6	['hydroxy', 'aromatic', 'amino', 'carbon', 'groups', 'ring', 'rings', 'bound', 'skeleton', 'atom']
7	['nitrogen', 'ligands', 'atom', 'complexing', 'least', 'one', 'ring', 'comprising', 'ruthenium', 'complexes']
8	['treatment', 'biological', 'waste', 'anaerobic', 'sewage', 'processes', 'water', 'temperature', 'alcohol', 'sludge']
9	['portion', 'mould', 'moulding', 'preform', 'runner', 'injected', 'flange', 'variable', 'components', 'two']
10	['microorganisms', 'yeasts', 'multiple', 'halogen', 'biofuels', 'substrate', 'cellulosic', 'cellulase', 'action', 'carbohydrase']
11	['magnetic', 'employing', 'electric', 'reactors', 'properties', 'processes', 'energy', 'characterised', 'mixing', 'spinels']
12	['cells', 'adapted', 'heat', 'interconnectors', 'protecting', 'keeping', 'batteries', 'exchange', 'shape', 'solid']
13	['fluid', 'bearings', 'sealing', 'cooling', 'gas', 'means', 'propulsion', 'aircraft', 'gaseous', 'lubricant']
14	['sulfides', 'selenides', 'tellurides', 'licofy', 'hydroxides', 'halogenides', 'compounds', 'electrodes', 'inorganic', 'based']
15	['substance', 'separated', 'constructional', 'screening', 'surfaces', 'screens', 'matrix', 'cleaning', 'acting', 'details']

16	['gasoline', 'boiling', 'range', 'oil', 'diesel', 'naphtha', 'well', 'fluids', 'cos', 'hcn']
17	['oxidoreductases', 'donors', 'leucine', 'acceptor', 'dehydrogenase', 'acting', 'group', 'acids', 'alanine', 'isoleucine']
18	['means', 'locks', 'locking', 'striker', 'data', 'safes', 'vaults', 'remotely', 'controlled', 'clothing']
19	['used', 'acids', 'thermoplastic', 'elastomer', 'fibers', 'biodegradable', 'polyurethanes', 'grafted', 'rubbers', 'epoxide']
20	['solvents', 'used', 'oils', 'solvent', 'single', 'extractive', 'sheets', 'extraction', 'refining', 'applications']
21	['atoms', 'carbon', 'hydrogen', 'unsaturation', 'five', 'four', 'saturated', 'dehydration', 'acyclic', 'double']
22	['ammonia', 'separation', 'liquors', 'without', 'moving', 'inside', 'vapours', 'sulfuric', 'absorbents', 'reactors']
23	['load', 'demand', 'response', 'shedding', 'peak', 'shaving', 'transactions', 'systems', 'energy', 'trading']
24	['acids', 'esters', 'starting', 'intermediate', 'peroxy', 'moiety', 'unreacted', 'precursors', 'ester', 'atom']
25	['crystalline', 'molecular', 'sieves', 'cracking', 'catalytic', 'oxides', 'steps', 'according', 'step', 'absence']
26	['wheels', 'wheel', 'disc', 'mounting', 'axle', 'mount', 'roller', 'skates', 'hubs', 'arrangement']
27	['technologies', 'arrangements', 'water', 'consumption', 'aiming', 'efficiency', 'home', 'appliances', 'induction', 'cooking']
28	['like', 'paper', 'ribs', 'flanges', 'framed', 'panels', 'spaced', 'wood', 'chips', 'vegetable']
29	['electronically', 'readable', 'memory', 'parts', 'cartridges', 'cartridge', 'attachment', 'positioning', 'regulation', 'connecting']
30	['reactive', 'dyes', 'colouring', 'agents', 'disazo', 'directly', 'heterocyclic', 'system', 'attached', 'mixtures']
31	['compositions', 'paints', 'varnishes', 'lacquers', 'coating', 'inorganic', 'diluents', 'nature', 'pastes', 'effects']
32	['water', 'industrial', 'household', 'valves', 'relating', 'pumps', 'supply', 'used', 'details', 'cooling']
33	['rings', 'unspecified', 'carbocyclic', 'hetero', 'radicals', 'condensed', 'heterocyclic', 'substituted', 'ring', 'oxygen']
34	['assessing', 'vulnerabilities', 'evaluating', 'computer', 'security', 'domains', 'executing',

	'restricted', 'sandbox', 'secure']
35	['collapsible', 'foldable', 'bottles', 'wall', 'structure']
36	['systems']
37	['emission', 'atmospheric', 'pm', 'smoke', 'microparticles', 'smog', 'aerosol', 'quality', 'improvement', 'preservation']

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117 Table S6: Overview of the top ten extracted keywords for each cluster from 2015 to 2024.

Cluster-ID	Central Keywords
0	['recycling', 'serviceable', 'reclaiming', 'fuel', 'batteries', 'accumulators', 'cells', 'parts', 'waste', 'obtaining']
1	['batteries', 'electrodes', 'hydroxides', 'oxides', 'inserting', 'intercalating', 'mixed', 'intercalation', 'insertion', 'lithium']
2	['batteries', 'storage', 'energy', 'cells', 'battery', 'testing', 'systems', 'measuring', 'circuits', 'arrangements']
3	['solutions', 'inorganic', 'salt', 'processes', 'hydroxides', 'oxides', 'filtration', 'generated', 'extraction', 'exchangers']
4	['li', 'diagram', 'sem', 'electric', 'two', 'obtained', 'properties', 'type', 'oxides', 'hydroxides']
5	['manufactured', 'micrometer', 'compositional', 'purity', 'final', 'product', 'manufacturing', 'production', 'metal', 'characterised']
6	['catalysts', 'one', 'least', 'atoms', 'compounds', 'type', 'hydroxy', 'ring', 'addition', 'groups']
7	['electrolysis', 'water', 'sources', 'production', 'hydrogen', 'gases', 'hydride', 'catalysts', 'containing', 'carbon']
8	['screens', 'separator', 'devices', 'screen', 'denying', 'egress', 'oversize', 'disintegrating', 'mechanisms', 'screening']
9	['diaphragms', 'membranes', 'characterised', 'material', 'separators', 'waste', 'processing', 'separation', 'choice', 'metal']
10	['saturated', 'carboxyl', 'groups', 'acids', 'esters', 'rings', 'carboxylic', 'containing', 'group', 'bound']
11	['cnhm', 'column', 'gas', 'stream', 'feed', 'separation', 'refrigeration', 'natural', 'gaseous', 'refinery']
12	['made', 'piece', 'contact', 'surface', 'one', 'paper', 'shape', 'discrete', 'locating', 'articles']
13	['oligosaccharides', 'five', 'saccharide', 'glycosidic', 'linkages', 'sugar', 'active', 'three',

	'radicals', 'attached']
14	['boring', 'cutting', 'stream', 'moving', 'cleaning', 'fluid', 'devices', 'conveyor', 'jet', 'conjunction']
15	['polymers', 'vinyl', 'derivatives', 'cellulose', 'co', 'acrylic', 'powder', 'particles', 'inorganic', 'thereof']
16	['reforming', 'step', 'monoxide', 'reaction', 'gasifying', 'carbon', 'vapour', 'hydrocarbons', 'containing', 'water']
17	['one', 'metallic', 'gaseous', 'electrode', 'power', 'exfoliation', 'photovoltaic', 'sensitive', 'attaching', 'trailing']
18	['memory', 'space', 'call', 'system', 'message', 'queues', 'buffers', 'shared', 'considering', 'execution']
19	['ammonium', 'fluorides', 'sulfates', 'sulfate', 'fluoride', 'sulfite', 'orthophosphates', 'calcium', 'fertilisers', 'preparing']
20	['networks', 'proprietary', 'networking', 'environments', 'medical', 'sensor', 'metering', 'transactions', 'measuring', 'variables']
21	['compositions', 'epoxy', 'polycarbonates', 'homopolymers', 'copolymers', 'resins', 'derivatives', 'compounds', 'polyesters', 'dicarboxylic']
22	['signals', 'cleaning', 'vehicles', 'acoustic', 'singals', 'ir', 'integral', 'tracks', 'spray', 'cleaned']
23	['liquid', 'effluents', 'oil', 'slurries', 'subject', 'circulatory', 'ascending', 'instrument', 'suspended', 'introduced']
24	['necks', 'bottles', 'apertures', 'held', 'together', 'slits', 'articles', 'packaging', 'containers', 'formed']
25	['constructions', 'cardboard', 'sachet', 'toiletry', 'cosmetic', 'adhesive', 'perfumes', 'labels', 'badges', 'releasability']
26	['carbonic', 'haloformic', 'carbonates', 'dehydration', 'amides', 'rare', 'earths', 'nitriles', 'dioxide', 'carboxylic']
27	['fluorine', 'hx', 'containing', 'compound', 'stabilisation', 'halogenated', 'halides', 'hydrocarbons', 'distillation', 'purification']
28	['ring', 'amines', 'indane', 'aromatisation', 'position', 'amino', 'condensed', 'skeleton', 'substitution', 'reduction']
29	['waste', 'heat', 'controlling', 'channels', 'recuperated', 'condensates', 'reclaiming', 'efficiency', 'media', 'distribution']
30	['form', 'elements', 'walls', 'wood', 'dismantled', 'concrete', 'recoverable', 'beams',

	'erection', 'shuttering']
31	['scrap', 'metal', 'consolidating', 'briquettes', 'strainers', 'briquetting', 'cars', 'compacting', 'permeable', 'casings']
32	['light', 'controlling', 'adapted', 'specially', 'omnidirectional', 'bulb', 'intensity', 'retrofit', 'led', 'colour']
33	['dynamics', 'cad', 'force', 'fluid', 'adapted', 'specially', 'equations', 'cfd', 'entry', 'interfaces']
34	['arrangements', 'fluent', 'means', 'liquid', 'material', 'excess', 'independently', 'preventing', 'deposits', 'blockage']
35	['spindles', 'elastic', 'twist', 'hollow', 'due', 'rather', 'twisting', 'fixing', 'backtwisting', 'imparting']
36	['management', 'power', 'computing', 'low', 'processors', 'configuring', 'program', 'initiating', 'registry', 'files']
37	['containing', 'dissolved', 'specified', 'removing', 'nitrogen', 'oxygen', 'compounds']
38	['effect', 'cooled', 'garments', 'peltier', 'means']
39	['nitro', 'atoms', 'groups', 'stabilisation', 'rings', 'substitution', 'bound', 'aromatic', 'purification', 'separation']
40	['government', 'public', 'services', 'certifying', 'business', 'benchmarking', 'key', 'indicator', 'kpi', 'performance']
41	['controllers', 'data', 'control', 'programme', 'numerical', 'employing', 'traffic', 'historical', 'logic', 'speed']
42	['situ', 'removing', 'surface', 'treatment', 'devices', 'material']
43	['parallely', 'network', 'generators', 'transformers', 'converters', 'converting', 'feeding', 'batteries', 'arrangements', 'single']

S8. Supplementary two-mode networks

To complement the two-mode networks shown in Figure 10, this section first presents the fully labelled two-mode networks filtered to include only nodes with a weight of 2 or more (Figure S8), followed by the completely unfiltered two-mode networks (Figure S9), in which only the clusters are labelled.

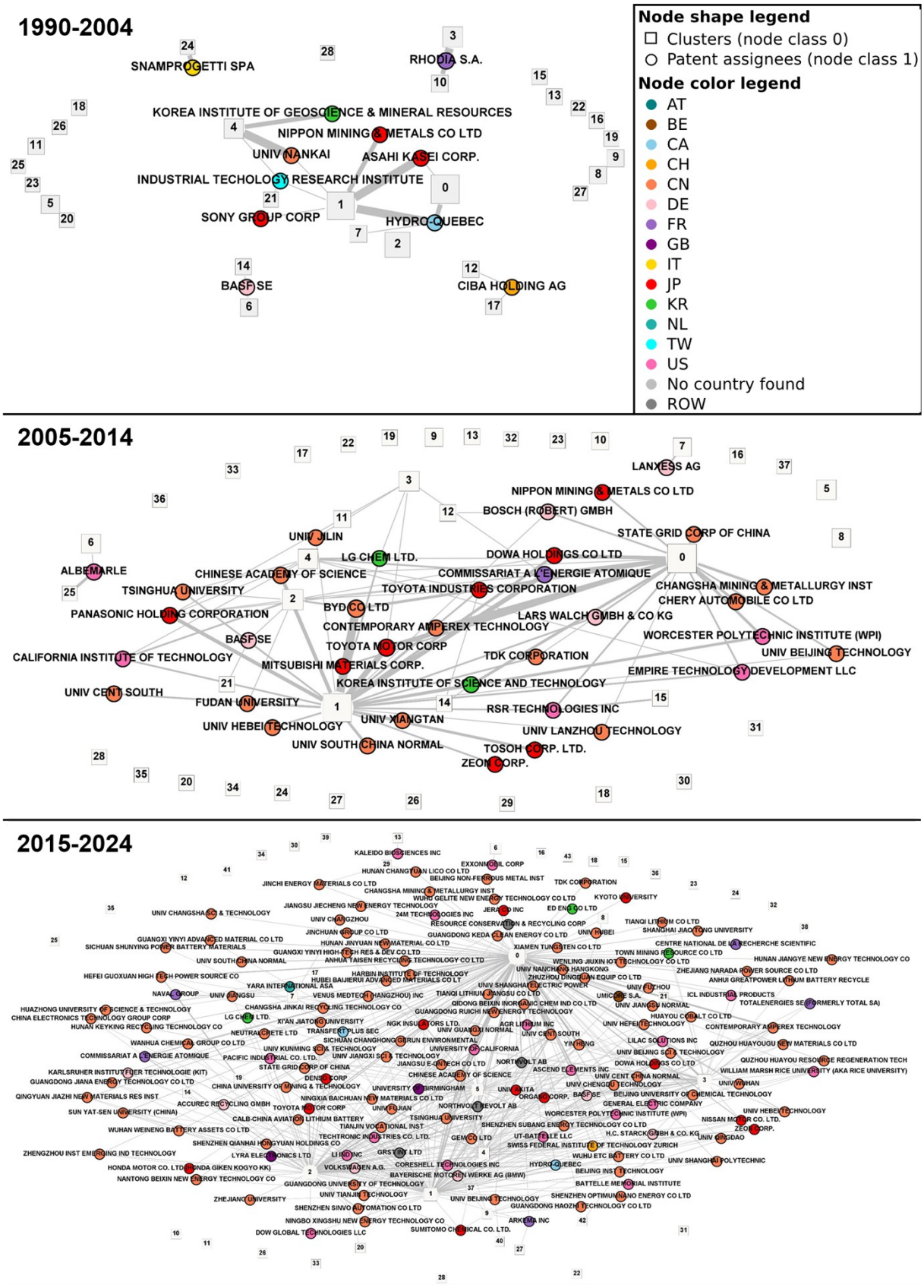

Figure S8: Overview of two mode networks (Knowledge areas and patent assignees) over three periods. Only nodes with a weight of ≥2 are displayed and labelled.

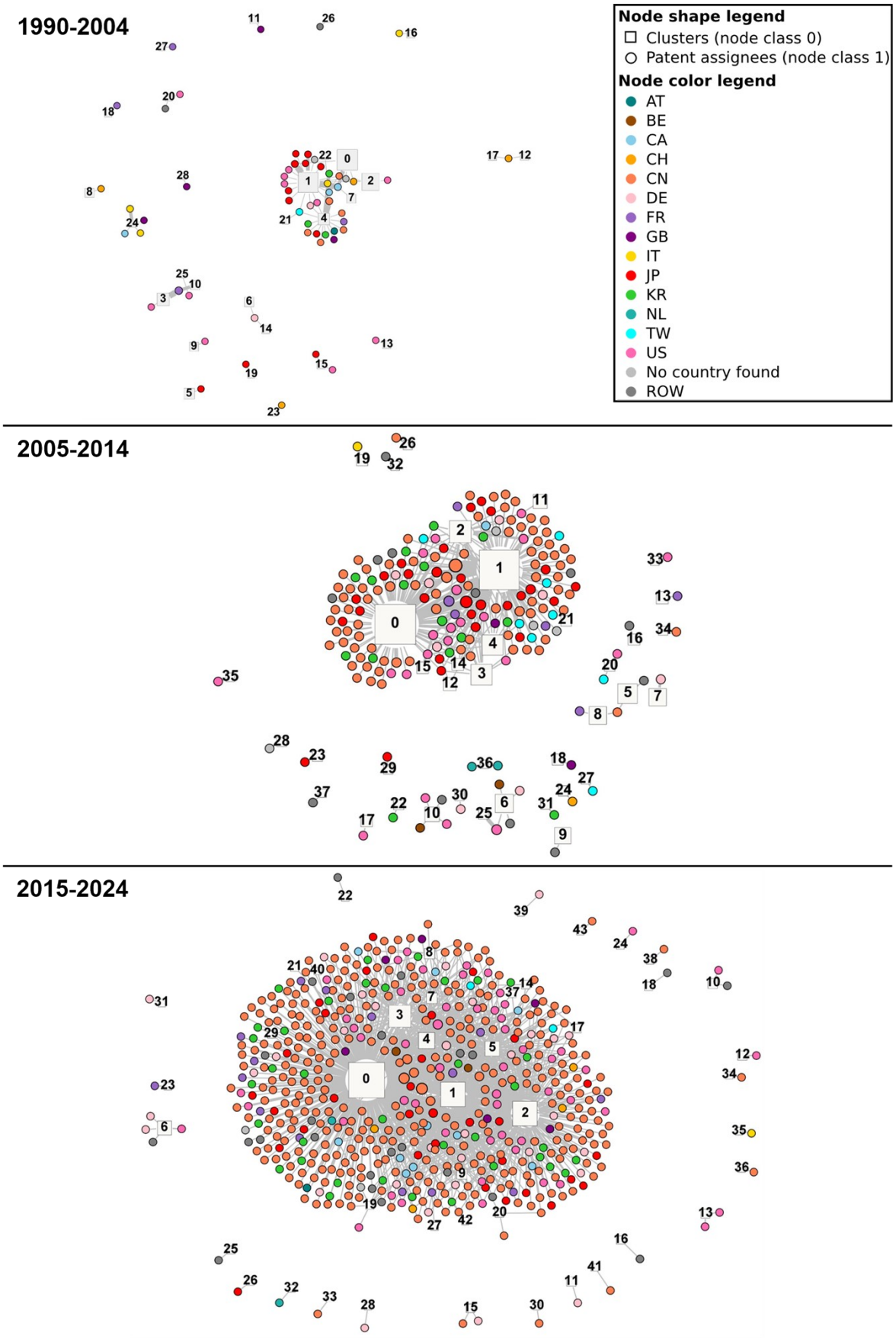

Figure S9: Overview of full two-mode networks (knowledge areas and patent assignees) over three periods. Patent assignees are not labelled.

S9. References

1 Y. Hu, Y. Yu, K. Huang and L. Wang, *J. Energy Storage*, 2020, **27**, 101111.

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