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Innovation Trends in Electrolysers for Hydrogen Production

Presenters:

- **Francesco PASIMENI, Associate Programme Officer, IRENA**
- **Geert BOEDT, Business Analyst, EPO**

TUESDAY, 7 JUNE 2022 • 14:00-14:30 CEST

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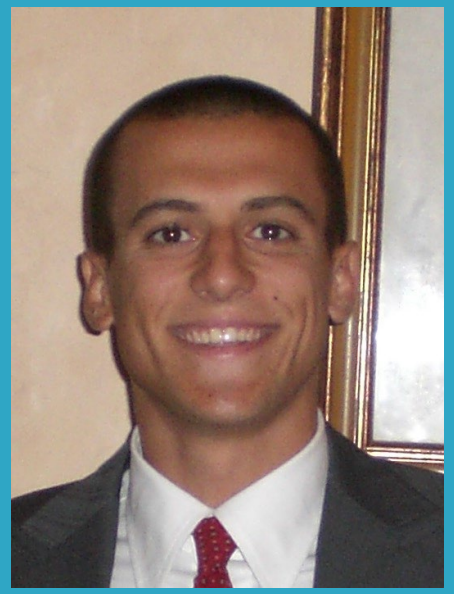
SPEAKERS



Francesco Pasimeni
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Innovation, Standards and Patents
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Geert Boedt
Business Analyst, Patent information officer Business Use of Patent Information,
EPO

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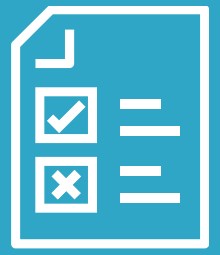
The **slides** and a **recording** at https://irena.org/events/2020/Jun/IRENA-Insights



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Demand for green hydrogen in a 1.5°C decarbonisation scenario

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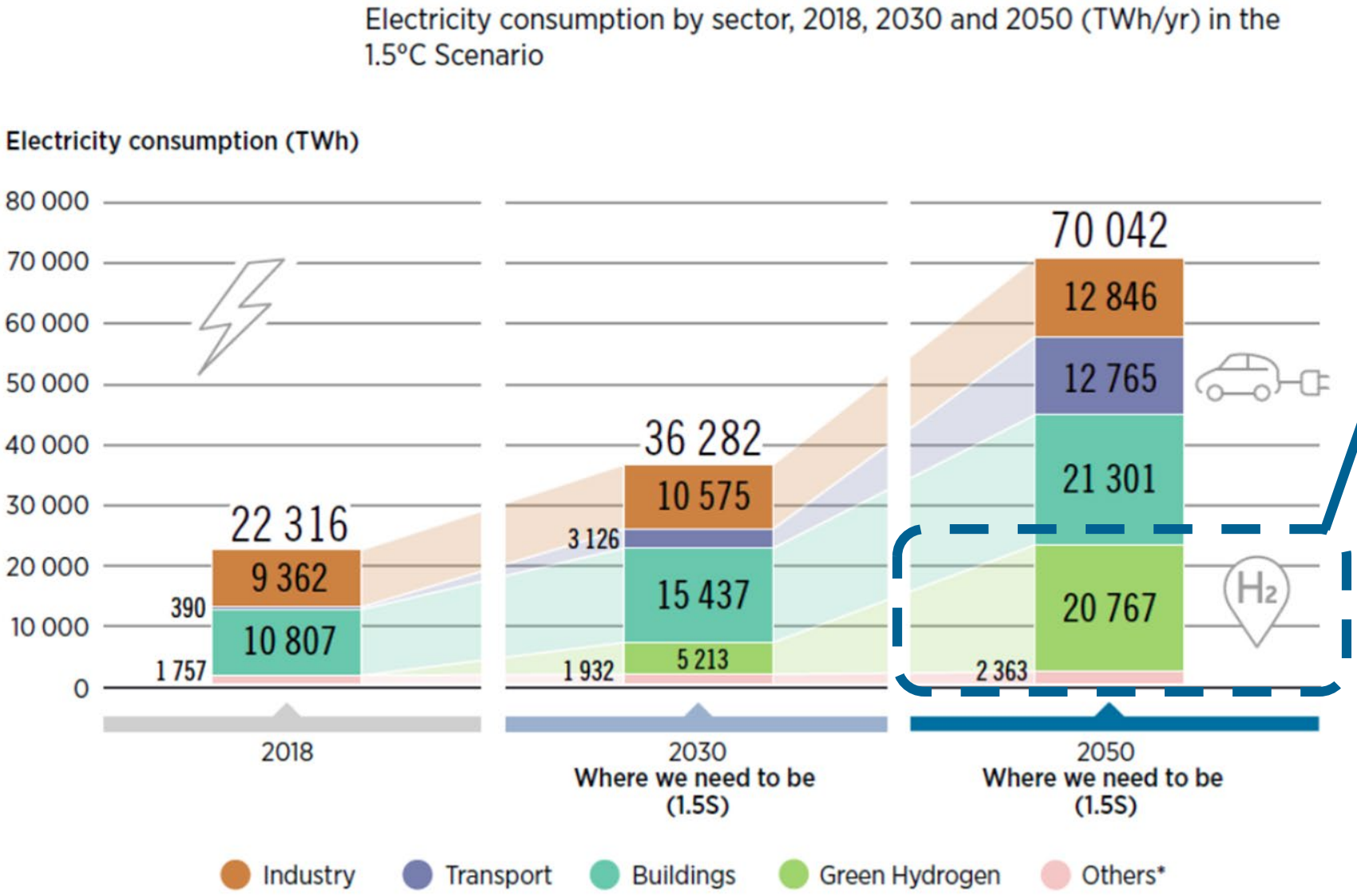

Key considerations

1- By 2050 more than 20,000 TWh of electricity demand for green hydrogen production – that is almost **as much electricity as we consume globally today**

2- We need a smart approach to **integrate electrolysers in power systems**, synergies with renewable generation

3- Key to **innovate to reduce the cost of electrolysers**

Source: https://www.irena.org/publications/2021/March/World-Energy-Transitions-Outlook

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IRENA works on green hydrogen

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EPO/IRENA Patent Insight Report:

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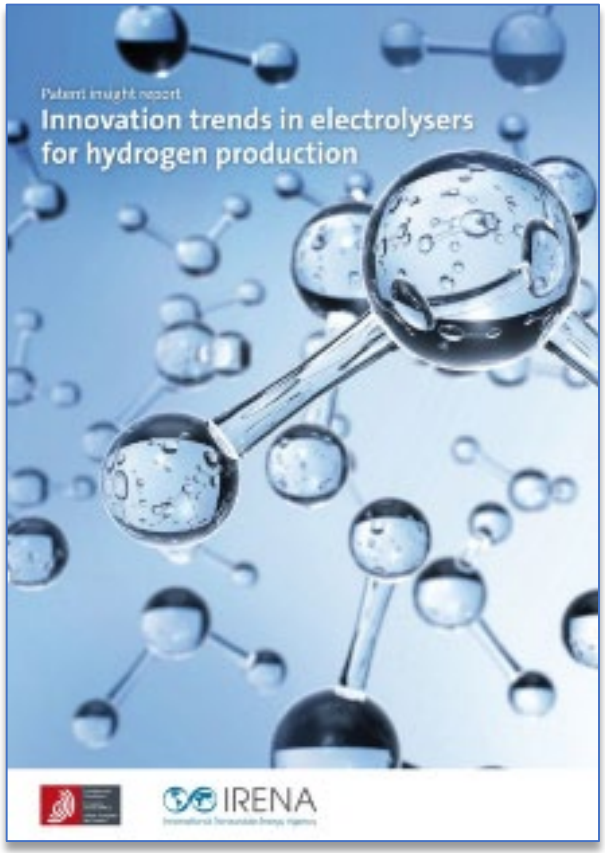
Innovation trends in electrolysers for hydrogen production



- In 2017, **IRENA & EPO** signed a memorandum of understanding on bilateral co-operation to promote innovation in the field of renewable energy technologies.
- This report tracks the **evolution of patent filings** over the last 15 years and highlights several trends.
- It aims to give **evidence** to useful to policymakers, technologists, companies, and investors wanting to better understand these rapidly expanding technology domains.

Outline

1. Methodology: using patent information
2. Results & discussion

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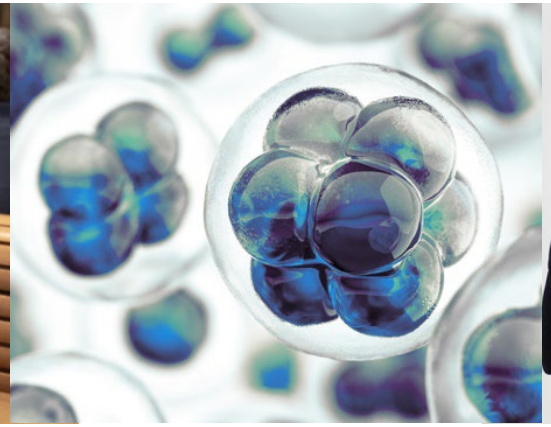
Europäisches Patentamt
European Patent Office
Office européen des brevets

Patent insight reports

Methodology

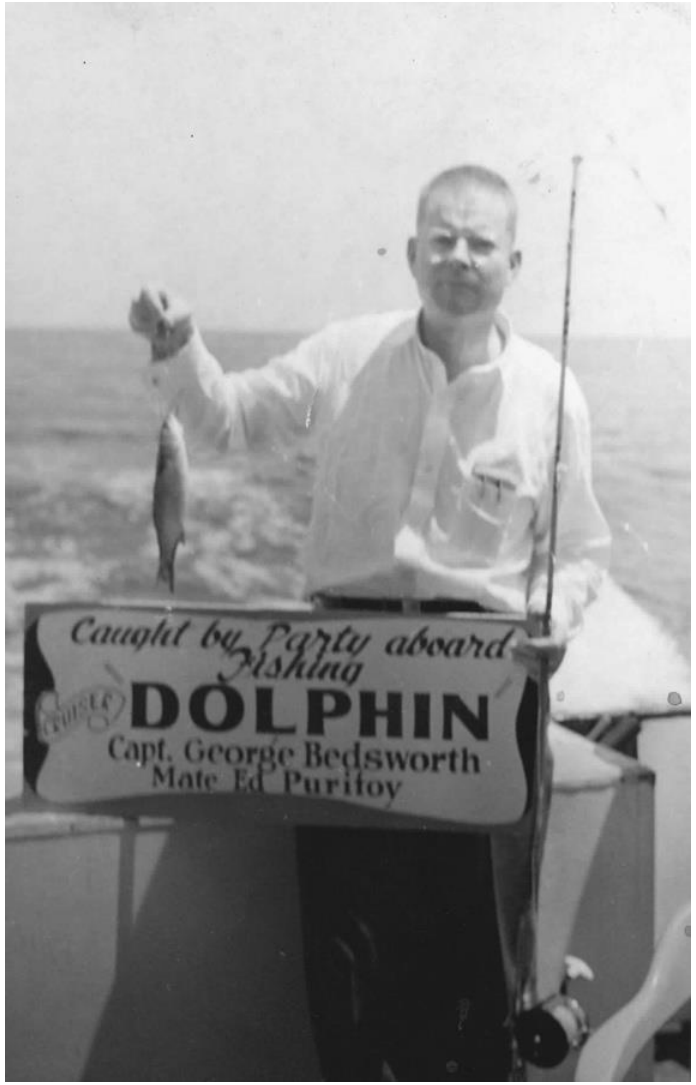



Photo courtesy of The W. Edwards Deming Institute®

"Without data, you're just another person with an opinion."

W. Edwards Deming

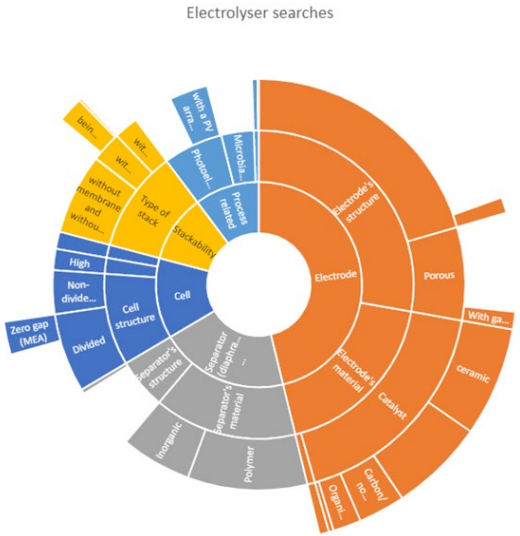
"Without an opinion,
you're just another person with data."

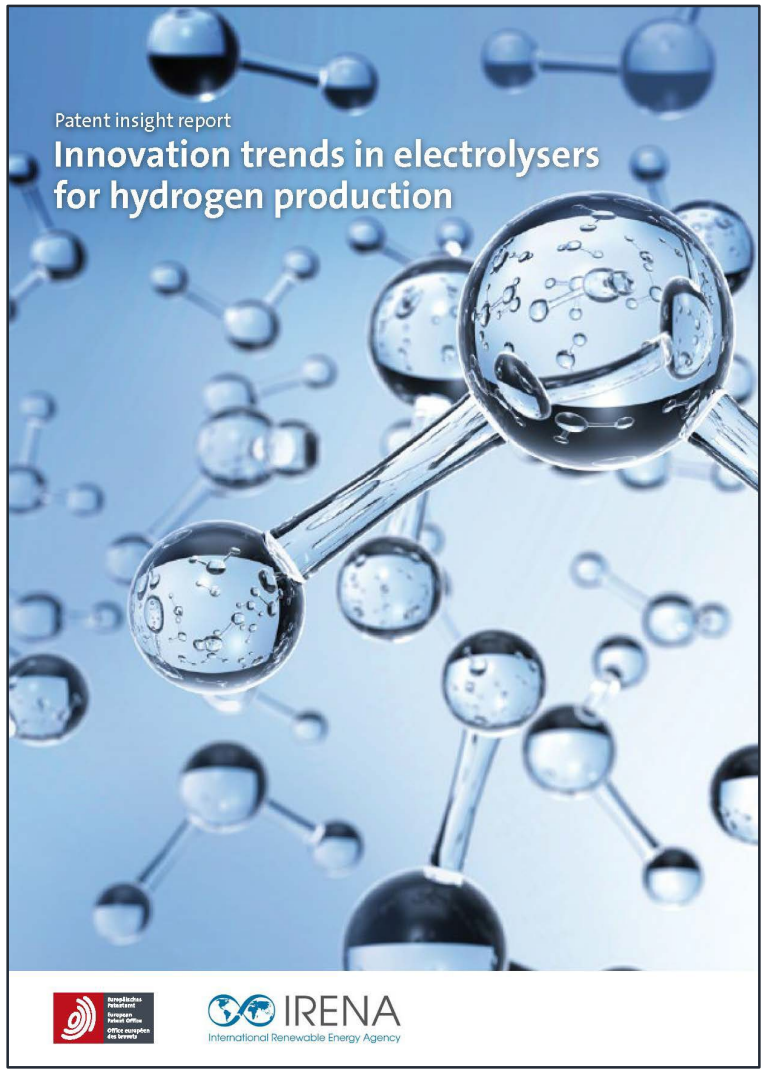
Given complexity of IP data … good luck …

Milo Jones and Philippe Silberzahn (Forbes)

Content

- **What are patent insight reports?**
- **Expert involvement**
- **Statistical analyses vs patentability search**
  - Technology map and query definition
  - Data cleaning
  - Data visualisation and interpretation





EPO patent insight reports

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- **Focus on future and emerging technologies**
- **Reports include**
  - search strategy to retrieve relevant information (based on public data)
  - key findings
- **Build on the expertise of the EPO's subject-matter experts in the technical field in cooperation with policy and business experts**
- **Methodology, data and results free to use**

www.epo.org/insight-reports

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European Patent Office
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EPO patent insight reports
Recent and planned activities

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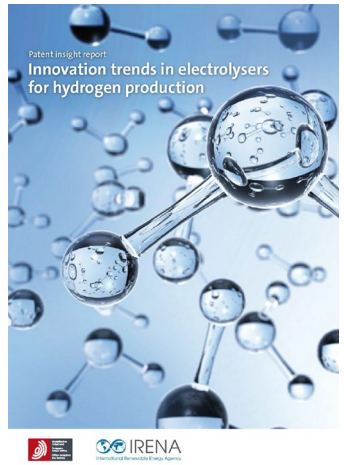
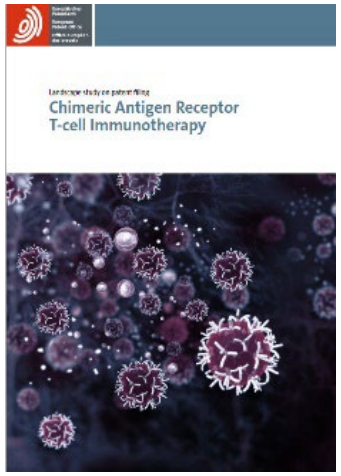
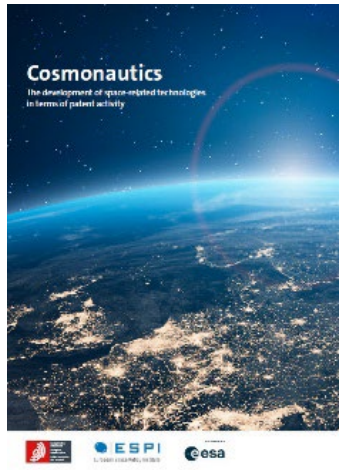
Topic	Status
Quantum metrology and sensing	Published (September 2019)
Chimeric antigen receptor T-cell immunotherapy	Published (December 2019)
Cosmonautics	Published (July 2021)
Quantum technologies and space	Published (November 2021)
Electrolysers for hydrogen production	Published (May 2022)
Offshore wind energy generation	Scheduled (2022)
Spaceborne sensing and green applications	Scheduled (2022)
Quantum computing	Planned (2022)







www.epo.org/insight-reports

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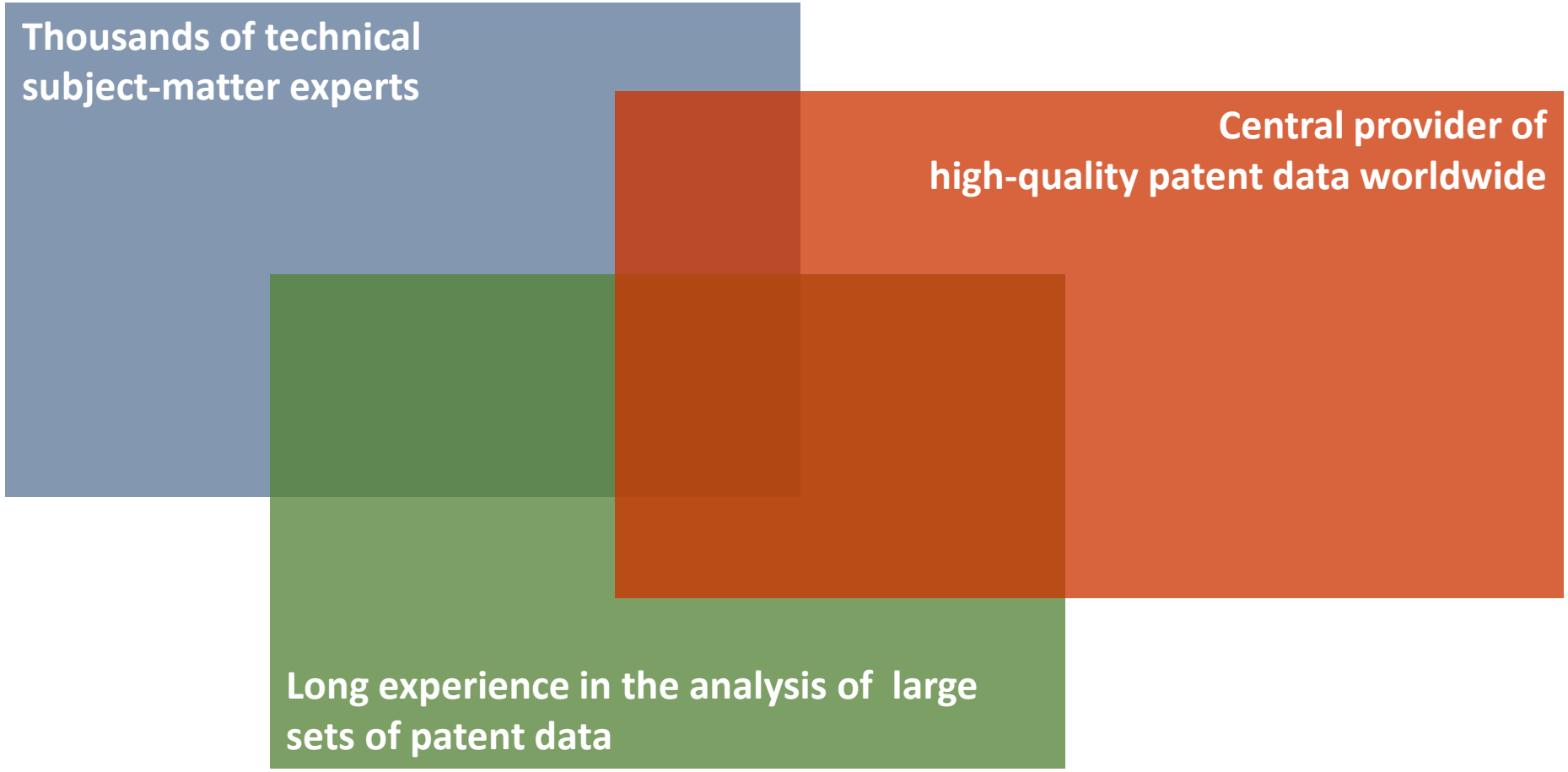
Patent analysis activities: Special position of the EPO



Searching ←→ Landscaping

Search Report

- Prior-art search
- Novelty search
- Freedom to operate search
- Invalidation search
- Bio sequence search
- Chemical structure searches

Limited list of patents

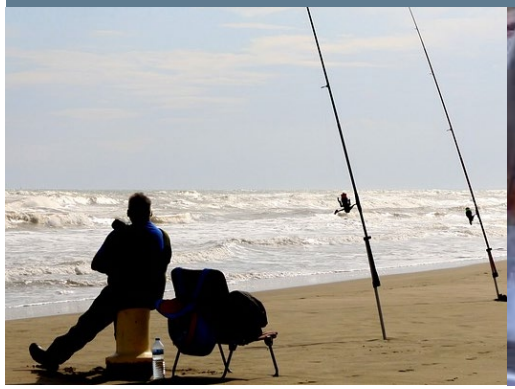
Analysis Report

- Technology trend analysis
- Activity monitoring
- Merger & acquisition
- Portfolio valuation
- (Cross) licencing
- Competitor watch
- Territorial mapping

Unlimited sample of patents

Searching ←→ Landscaping

Search Report

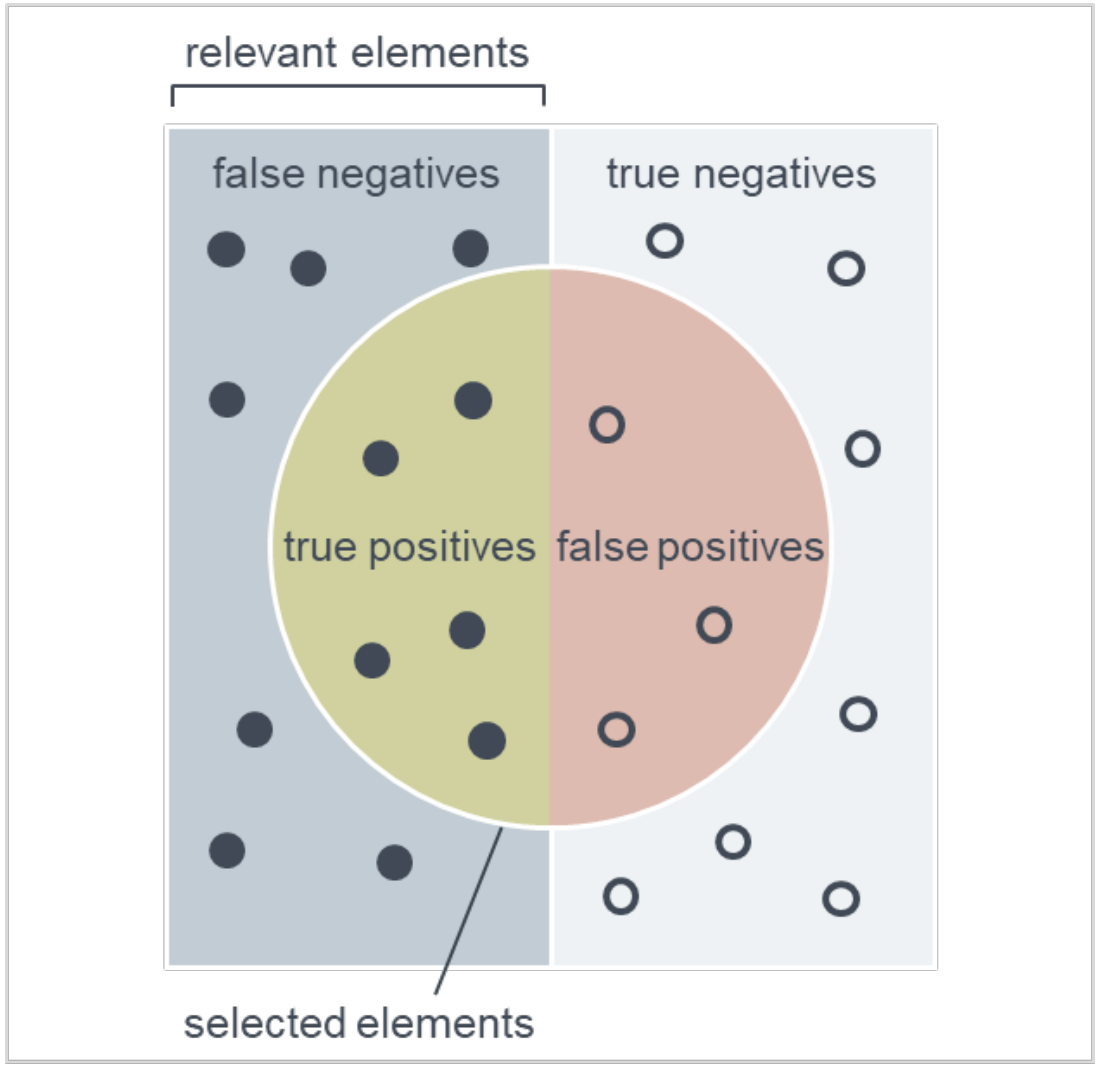


Analysis Report

Limited list of patents

Unlimited sample of patents

Precision and Recall of the sample data

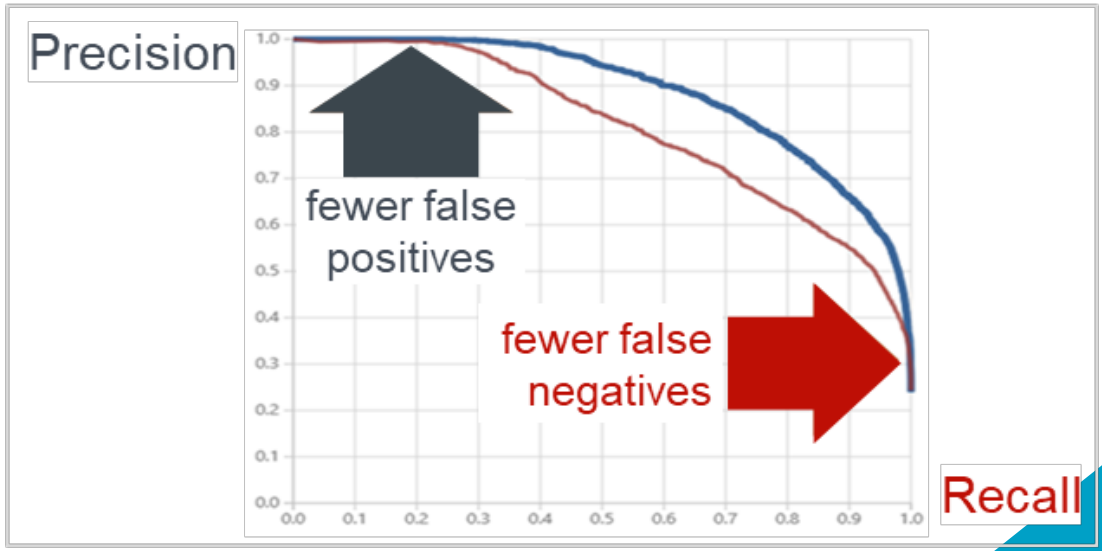


How many selected items are relevant?

Precision = $\frac{\text{true positives}}{\text{selected elements}}$

How many relevant items are selected?

Recall = $\frac{\text{true positives}}{\text{relevant elements}}$



https://en.wikipedia.org/wiki/Precision_and_recall

Methodology - Patent insight reports

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Preparation

- Select co-operation partners
- Identify relevant technology fields
- Consult with experts (external and examiners)

Collection and analyses

- Develop queries (key words, classifications)
- Improve precision and recall
- Statistical analyses

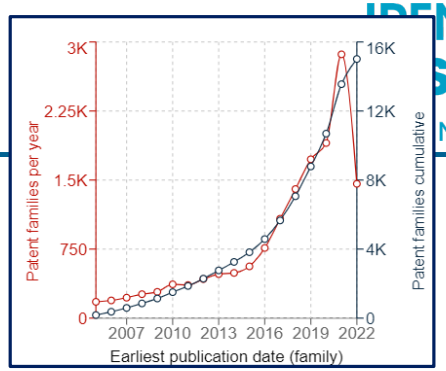
Insight

- Visualise dataset and trends
- Identify connections, correlations and networks
- Formulate insights, intelligence and conclusions

Knowledge sharing and training

- Explain approach
- Share
  - Queries
  - Best practices
  - Lessons learned
- Training

Identify relevant technology fields



Water electrolysis (Q01)

Cell operation conditions and structure	Electrocatalyst materials	Separator (diaphragm, membrane)	Stackability of electrolysers	Photoelectrolysis
– Temperature (Q04, Q05)	– Carbon (Q15, Q16, Q20)	– Polymer (organic) (Q24)	– with bipolar elements being plates (Q26)	– with PV power source (Q30)
– Pressure conditions (Q06, Q07)	– Metals and ceramics (Q17, Q18)	– Inorganic (ceramic mostly) (Q25)	– with bipolar elements being electrodes (Q27)	– with photoelectrode, photoabsorber a. electrocatalyst (Q31)
– Cell structure (Q08. Q09, Q10)	– Noble metals (Q19)		– with membranes (Q28)	– with photoelectrode, with photo-electrocatalyst (Q32)
			– without bipolar elements (Q29)	

Examples Query in ESPACENET:

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Q19: Electrocatalyst materials → Noble metals or noble metal oxides

(cl = "C25B11/081" OR cl = "C25B11/097" OR cl = "C25B11/093" OR (cl any "C25B11/075 C25B11/04 C25B11/089 C25B11/091" AND (ctxt any "platinum gold silver ruthenium iridium rhodium palladium rhenium osmium" OR claims any "RU??? PD??? RH??? OS???"))

4.693 patent families → 4.757 patent families

Classification	Description
C25B11/081	Electrodes: the element being a noble metal
C25B11/097	Electrodes: comprising two or more noble metals or noble metal alloys
C25B11/093	Electrodes with at least one noble metal or noble metal oxide and at least one non-noble metal oxide
C25B11/075	Electrodes consisting of a single catalytic element or compound + "platinum gold silver ruthenium iridium rhodium palladium rhenium osmium"

Examples Query in ESPACENET:

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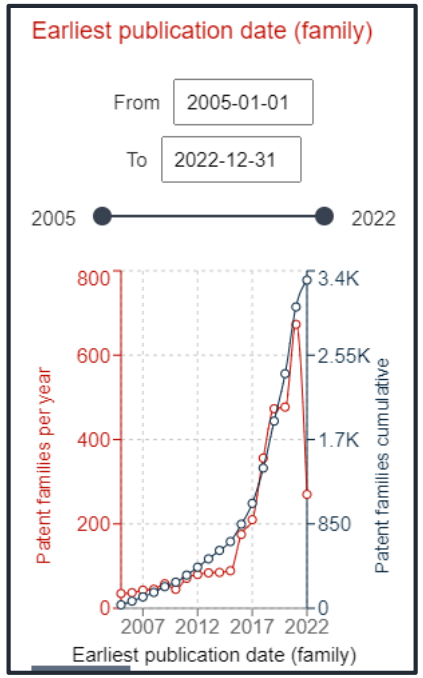
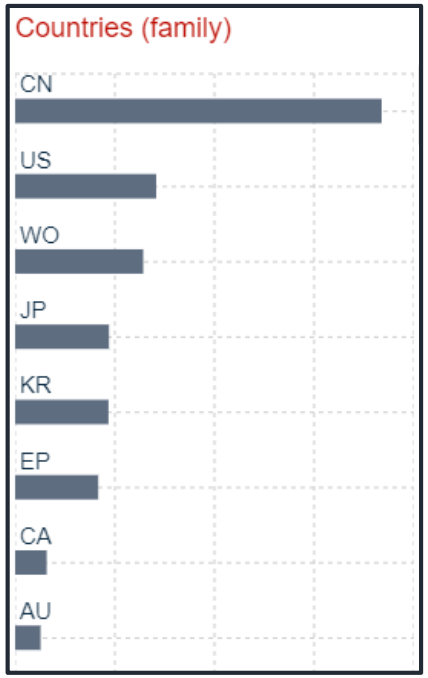
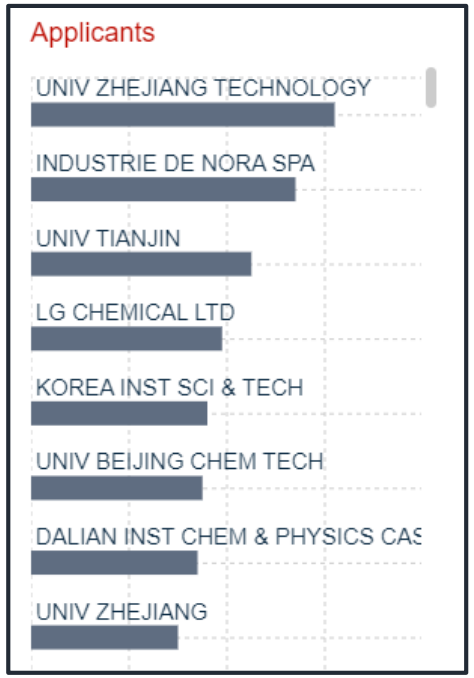
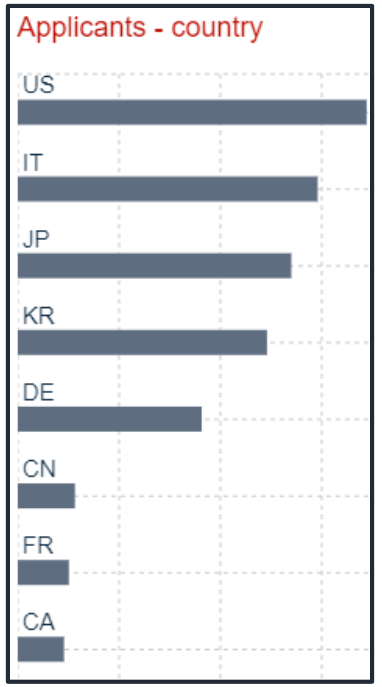
Q19: Electrocatalyst materials → Noble metals or noble metal oxides

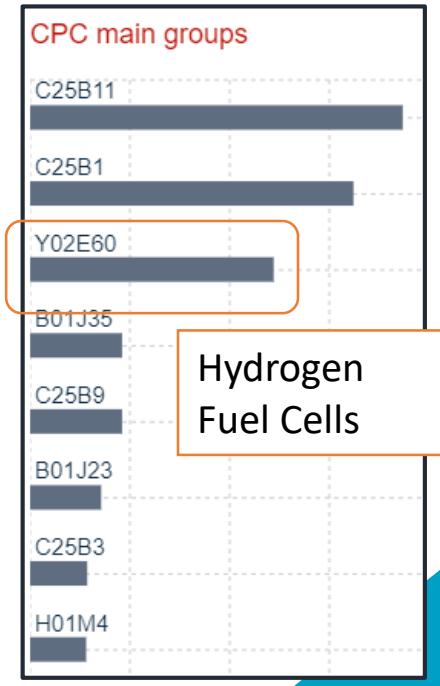
(cl = "C25B11/081" OR cl = "C25B11/097" OR cl = "C25B11/093" OR (cl any "C25B11/075 C25B11/04 C25B11/089 C25B11/091" AND (ctxt any "platinum gold silver ruthenium iridium rhodium palladium rhenium osmium" OR claims any "RU??? PD??? RH??? OS???"))











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Data cleaning

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- **Name harmonisation**

Harmonised name	Variations
DE NORA (IT)	DE NORA HOLDINGS / DE NORA PERMELEC / DE NORA TECHNOLOGY / INDUSTRIE DE NORA / PERMELEC ELECTRODE / DENORA / DE NORA
NTT (JP)	NTT NIPPON TELEGRAH & TELEPHONE / NIPPON TELEGRAPH & TELEPHONE / NTT DOCOMO
SAMSUNG (KR)	SAMSUNG ELECTRONICS / SAMSUNG ELECTRO MECHANICS / SAMSUNG ENGINEERING / SAMSUNG HEAVY INDUSTRIES / SAMSUNG SDI / SAMSUNG TOTAL PETROCHEMICALS

Data cleaning

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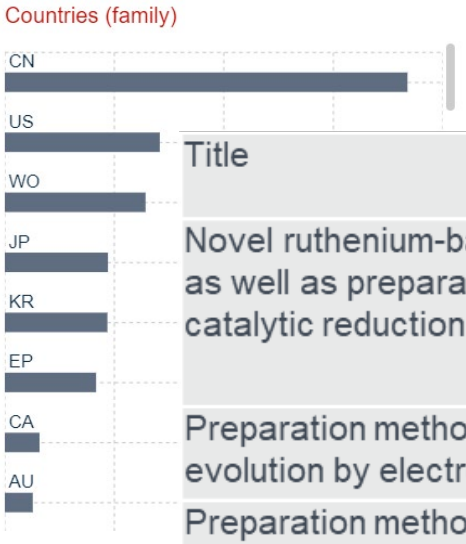
- **Problem to be solved ?**
- **Strong over-representation of single patent families in China**



Title	Applicants	Publication number	Pub_year	Family size
Novel ruthenium-based self-supporting electro-catalytic material as well as preparation method and application thereof to electro-catalytic reduction of nitrogen gas to produce ammonia	UNIV LIAONING	CN110624540A	2019	1
Preparation method of Co-Ni-P/fs-Si material for hydrogen evolution by electrolyzing water	UNIV CHANGCHUN SCIENCE & TECH	CN110607532A	2019	1
Preparation method of metal and alloy nanocrystalline	UNIV QINGDAO	CN110578069A CN110578069B	2019	1
Method for synthesizing 1-naphthol compound based on electrochemical intermolecular cyclization	UNIV GUANGXI NORMAL	CN110552018A CN110552018B	2019	1
Method for preparing Ag supported quasi-three-dimensional structure embedded flexible electrode material	UNIV NORTHEASTERN QINHUANGDAO	CN110629250A CN110629250B	2019	1
Method for efficiently and simply synthesizing ruthenium (Ru) nanometer crystals different in morphology	UNIV SHANGQIU NORMAL	CN110625135A CN110625135B	2019	1

Data cleaning

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- **Problem to be solved ?**
- **Strong overrepresentation of single patent families in China**

→ introduce concept of "International Patent Family"

IPF: patents that have more than one country in the list of publications, applicants, inventors or first priority countries.

- **Advantages: single national filings are excluded**
- **Easy to implement from a data aggregation point of view.**
- **"Higher quality" of patents in data sample –> representative for higher impact**

Visualisation and insight with Excel charts and Tableau workbook

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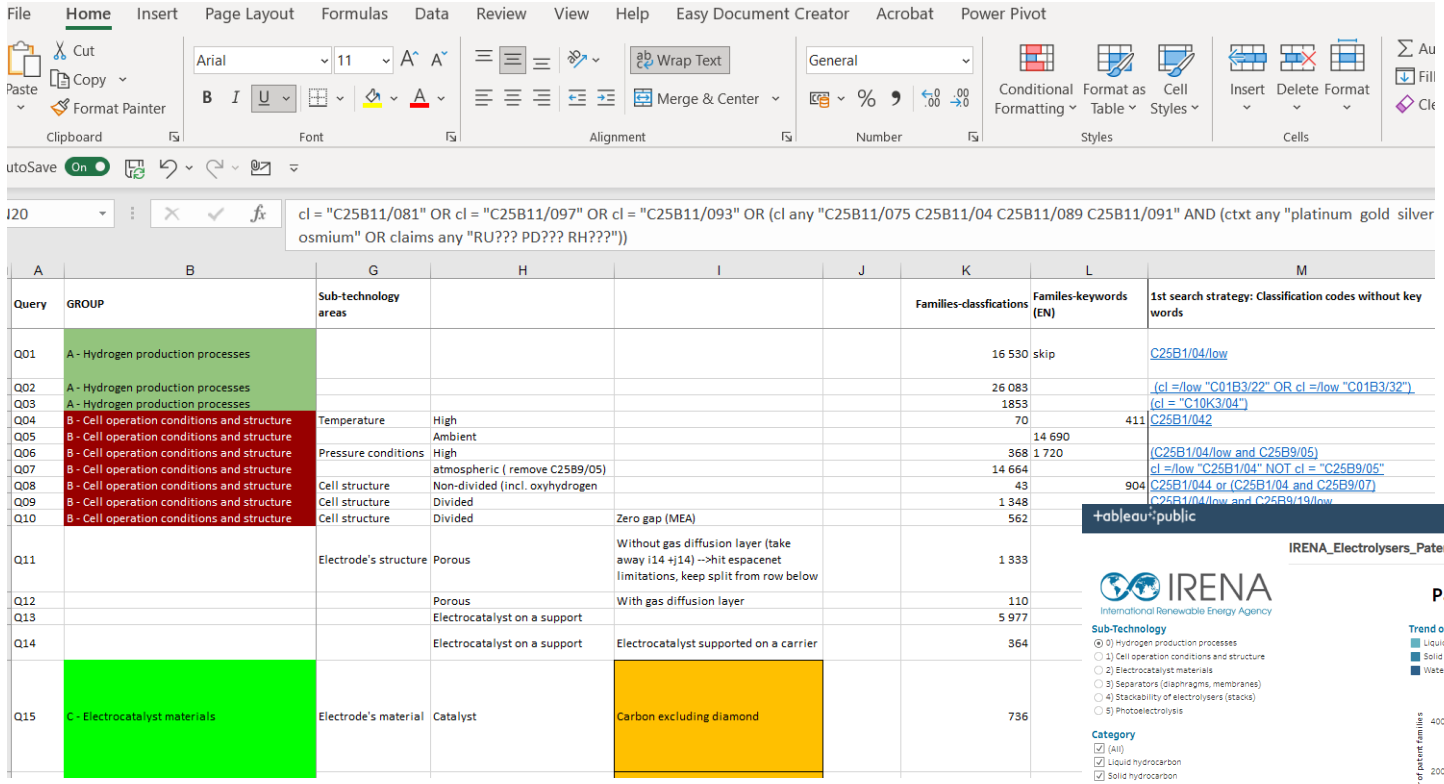
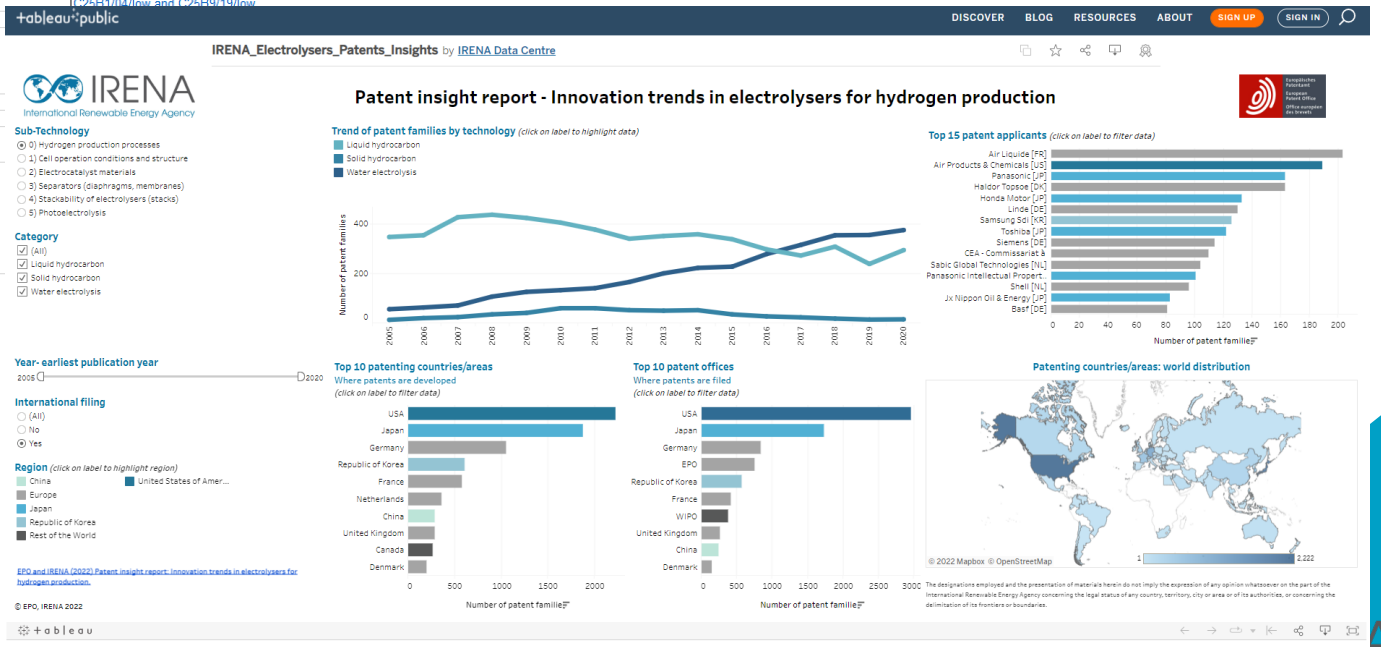


Query	GROUP	Sub-technology areas				Familes-classfications	Familes-keywords (EN)	1st search strategy: Classification codes without key words
Q01	A - Hydrogen production processes					16 530	skip	C25B1/04/low
Q02	A - Hydrogen production processes					26 083		(cl =/low "C01B3/22" OR cl =/low "C01B3/32")
Q03	A - Hydrogen production processes					1853		(cl = "C10K3/04")
Q04	B - Cell operation conditions and structure	Temperature	High			70	411	C25B1/042
Q05	B - Cell operation conditions and structure		Ambient				14 690	
Q06	B - Cell operation conditions and structure	Pressure conditions	High			368	1 720	(C25B1/04/low and C25B9/05)
Q07	B - Cell operation conditions and structure		atmospheric (remove C25B9/05)			14 664		cl =/low "C25B1/04" NOT cl = "C25B9/05"
Q08	B - Cell operation conditions and structure	Cell structure	Non-divided (incl. oxyhydrogen			43	904	C25B1/044 or (C25B1/04 and C25B9/07)
Q09	B - Cell operation conditions and structure	Cell structure	Divided			1 348		C25B1/04/low and C25B9/19/low
Q10	B - Cell operation conditions and structure	Cell structure	Divided	Zero gap (MEA)		562		
Q11		Electrode's structure	Porous	Without gas diffusion layer (take away i14 +j14) -->hit espacenet limitations, keep split from row below		1 333		
Q12			Porous	With gas diffusion layer		110		
Q13			Electrocatalyst on a support			5 977		
Q14			Electrocatalyst on a support	Electrocatalyst supported on a carrier		364		
Q15	C - Electrocatalyst materials	Electrode's material	Catalyst	Carbon excluding diamond		736		



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Usage and promotion

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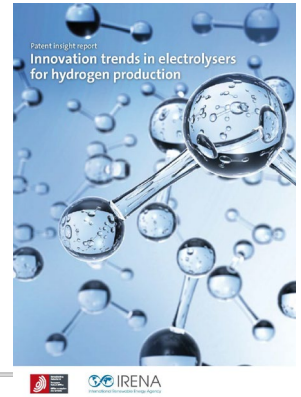
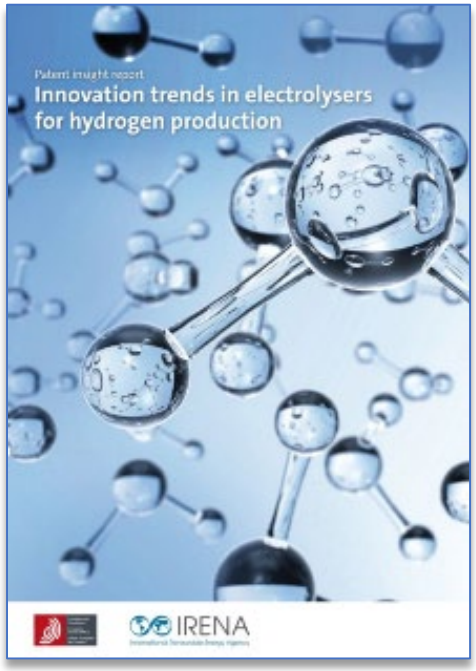
Potential success factors

- Launch at Patent Knowledge Week
- Events of co-operation partners
- Promotion in social media
- Newsflash and trainings
- Presentation at conferences





Key Findings

Water electrolysis taking the lead for hydrogen production

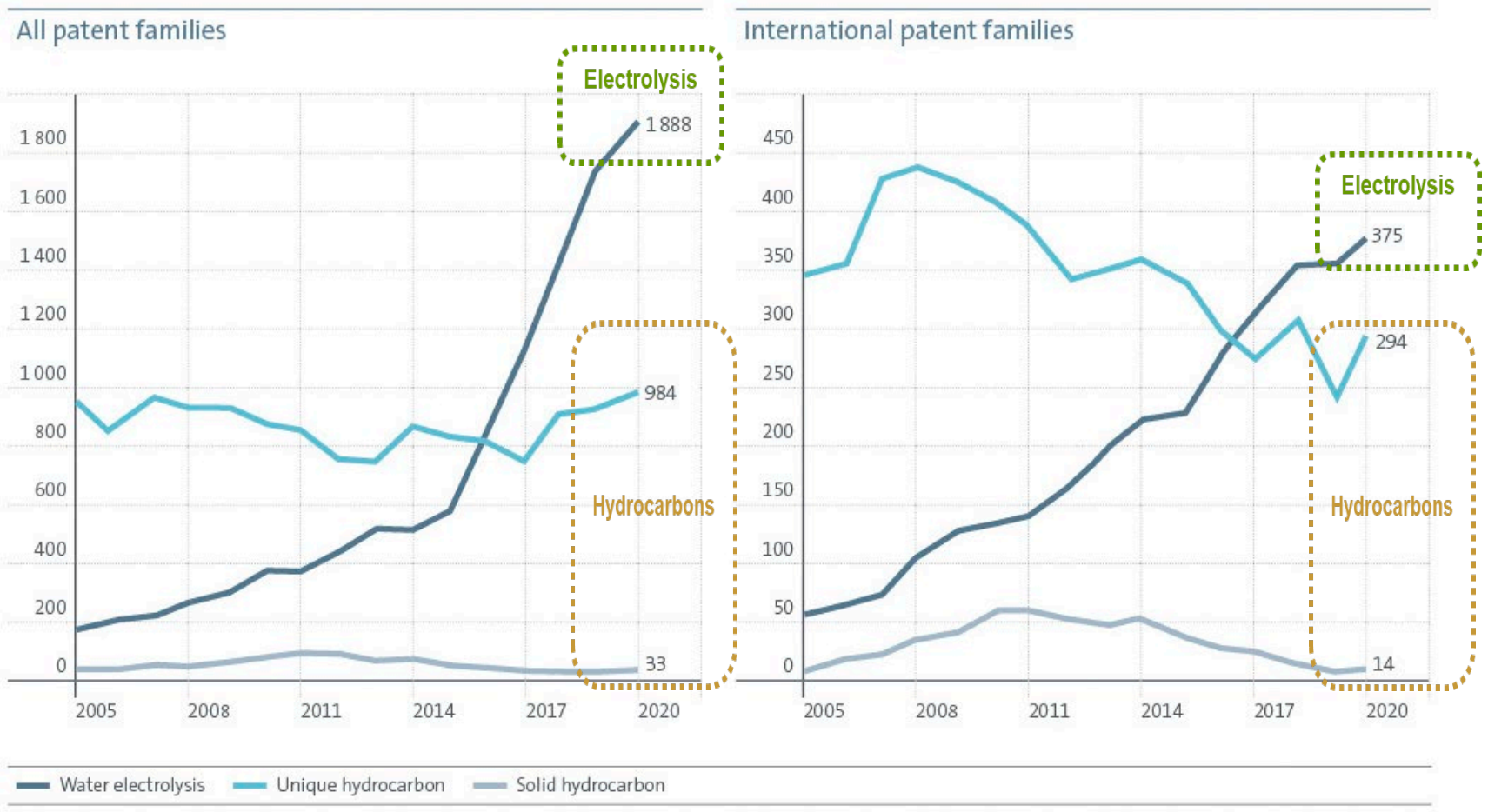


Figure 2: This figure shows the 2005-2020 trend of patent families (left-hand side) and international patent families (right-hand side), comparing hydrogen production processes based on water electrolysis with processes using liquid or solid hydrocarbon feedstock.

- From 2005, **+18% each year** for hydrogen production technologies
- In 2016, IPFs for **water electrolysis** > to IPFs for hydrogen from hydrocarbons
- JP+US+DE = **52%** of total IPFs
- CN IPFs only **3%** of the total (>60% other countries)
- **JP and US** most targeted countries (>50%), but KR, CN and DE are getting relevance
- **JP companies** (Toshiba, Panasonic & Honda) active in electrolysis.
- Top10 in hydrocarbon (2005-2014) diminish IPFs in later period (2015-2020)

5 sub-technologies relevant for reducing the cost of electrolysis of water

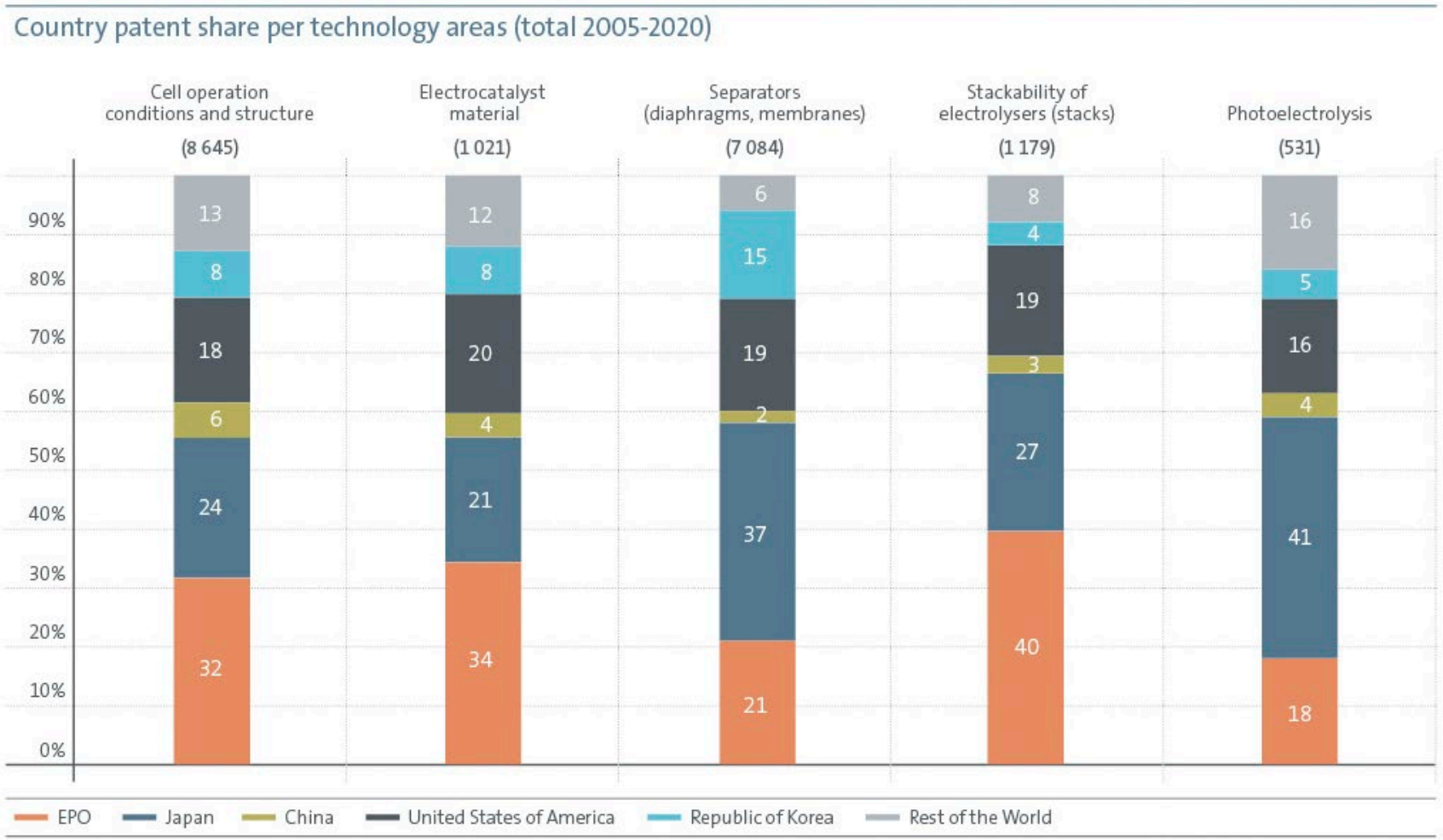


Figure 7: This is a summary chart of the country share of international patents in relation to the five subtechnology areas identified. The country refers to the country of the patent applicants. Europe groups together the 38 member states of the European Patent Organisation.[21] Numbers in bold and in parenthesis at the top of each column are the total number of international patent applications in that technology area.

- **Europe & JP: 50%** of the total IPFs filed in all areas
- **Europe** leads in the stackability of electrolysers (41%), electrocatalyst material (34%) and cell operation conditions and structure (32%)
- **Japan** first in photoelectrolysis (39%) and separators (diaphragms, membranes) (36%).
- **USA** averages 18% across all technology areas
- **Rep. of Korea** highest share in separators (diaphragms, membranes) (16%)
- **China** 4% international patents but dominates domestic filings.

Cells operating at higher pressure may reduce costs for green hydrogen production

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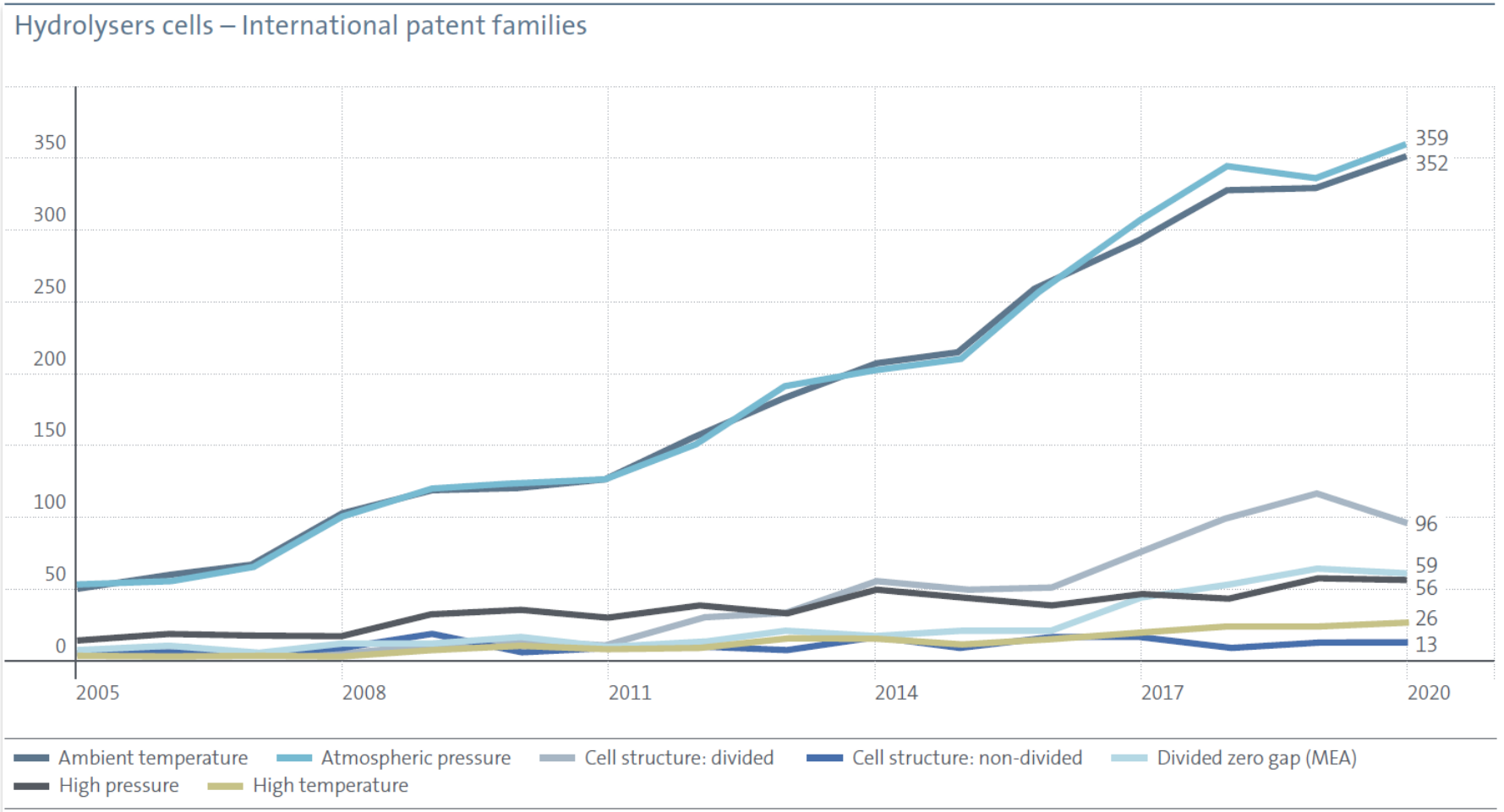

Figure 8: This figure shows the 2005-2020 trend of international patent families focusing on the following electrolyser cell operating parameters: ambient temperature, atmospheric pressure, cell structure: divided, cell structure: non-divided, divided zero gap (membrane electrode assembly or MEA), high pressure and high temperature.

- Cells operating at atmospheric pressure and ambient temperature: **+70%** between 2015 and 2020
- 2020 almost **double** 2016 high pressure, divided zero gap and divided cell structure technology, for which the number of patent
- JP and USA lead, followed by DE, KR, FR and CN: **80%** of total IPFs 2016-2020

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Scarce materials are a major barrier to electrolyser cost and scale-up. Solutions to replace such materials are needed (i.e., using non-noble metals)

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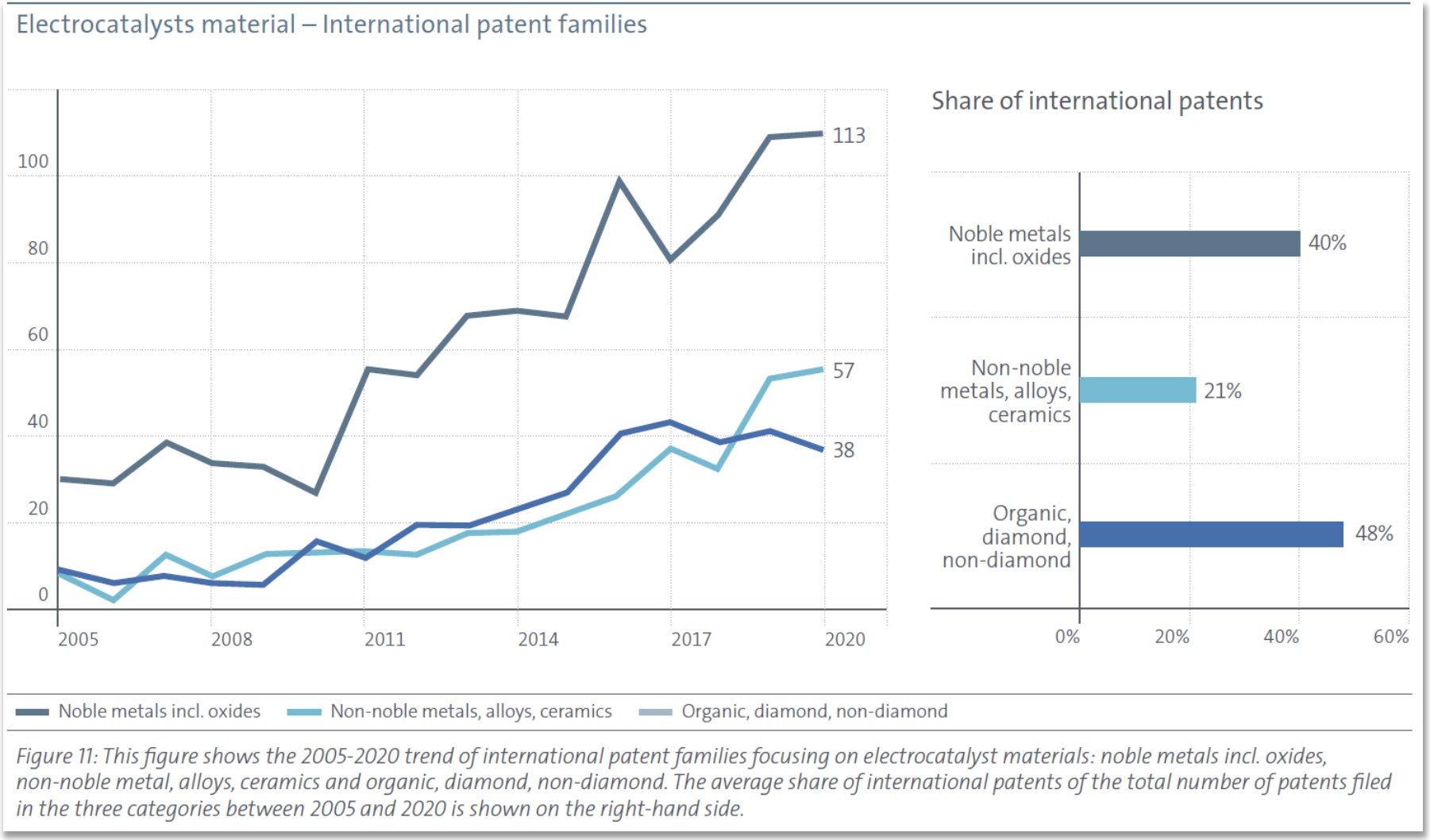

Figure 11: This figure shows the 2005-2020 trend of international patent families focusing on electrocatalyst materials: noble metals incl. oxides, non-noble metal, alloys, ceramics and organic, diamond, non-diamond. The average share of international patents of the total number of patents filed in the three categories between 2005 and 2020 is shown on the right-hand side.

- From **2011**: IPFs increase for technology using noble metals
- From **2015**:IPFs steady increase for non-noble metals, alloys and ceramics → may reduce materials costs
- In **2019**: non-noble metals and ceramics overtook the organic, diamond and non-diamond category
- JP+US cover about **42%** in all three technology areas

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Reducing membrane thickness enables an increase in efficiency, and enables a reduction in electricity consumption

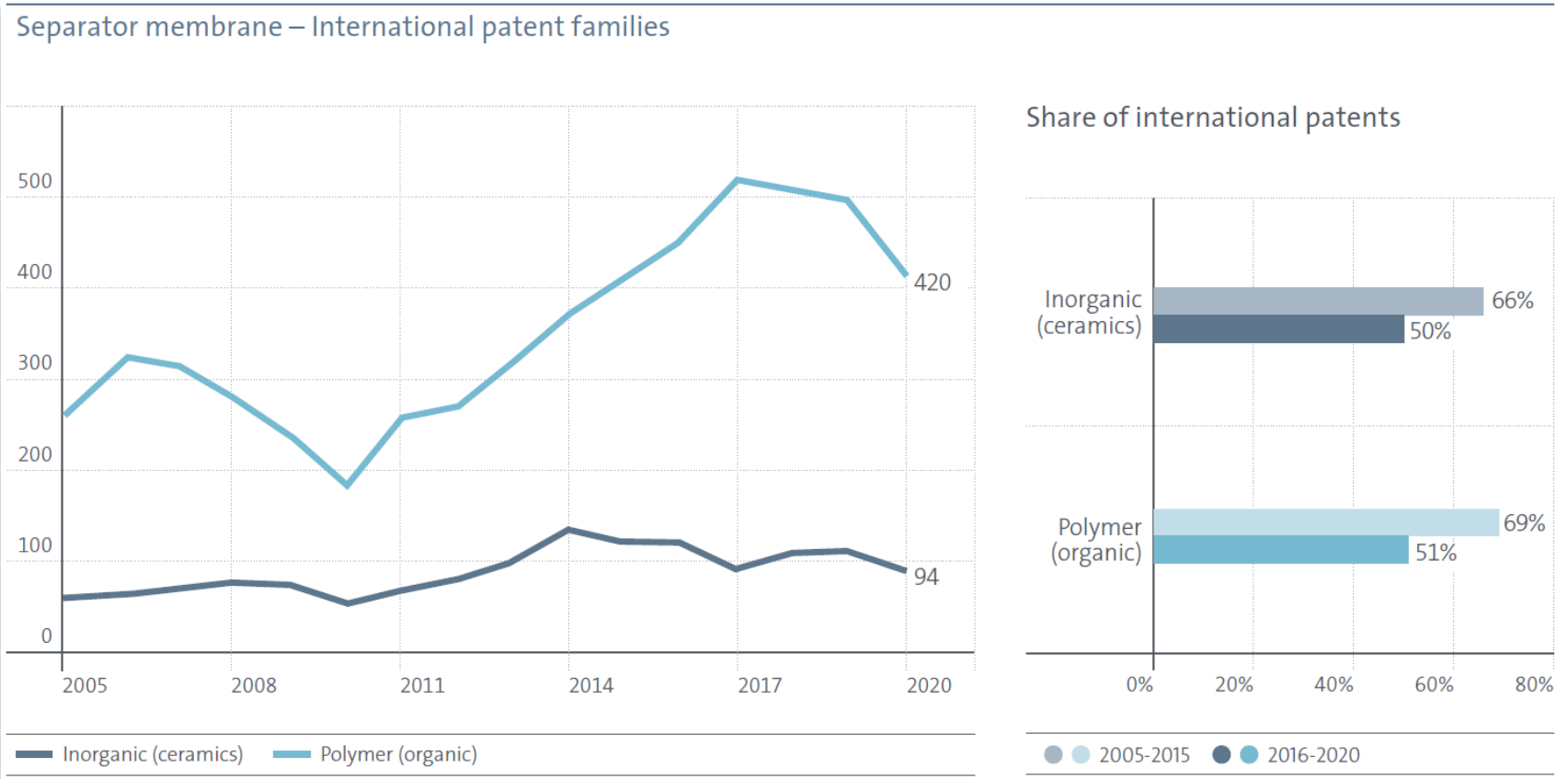

Figure 14: This figure shows the 2005-2020 trend of international patent families focusing on separator membranes: inorganic (ceramic) and polymer (organic). The average share of international patents of the total patents filed in 2005-2015 and in 2016-2020 is shown on the right-hand side.

- IPFs on inorganic (ceramic) separator membranes **overall stable**, but tripled in 2010-2014
- IPFs on polymer (organic) membranes **rapid increase** after 2010 and until **2017** (then reduce)
- More IPFs in **2016-2020** than 2005-2015
- **JP+US 60%** of total IPFs in inorganic (ceramic) separator membranes
- **JP** focuses on polymer (organic) membranes (37%), but 2018-2020 **USA, KR and DE** increase compared to past

Increasing stack production to automated production in GW scale manufacturing facilities to achieve a cost reduction by economy of scale

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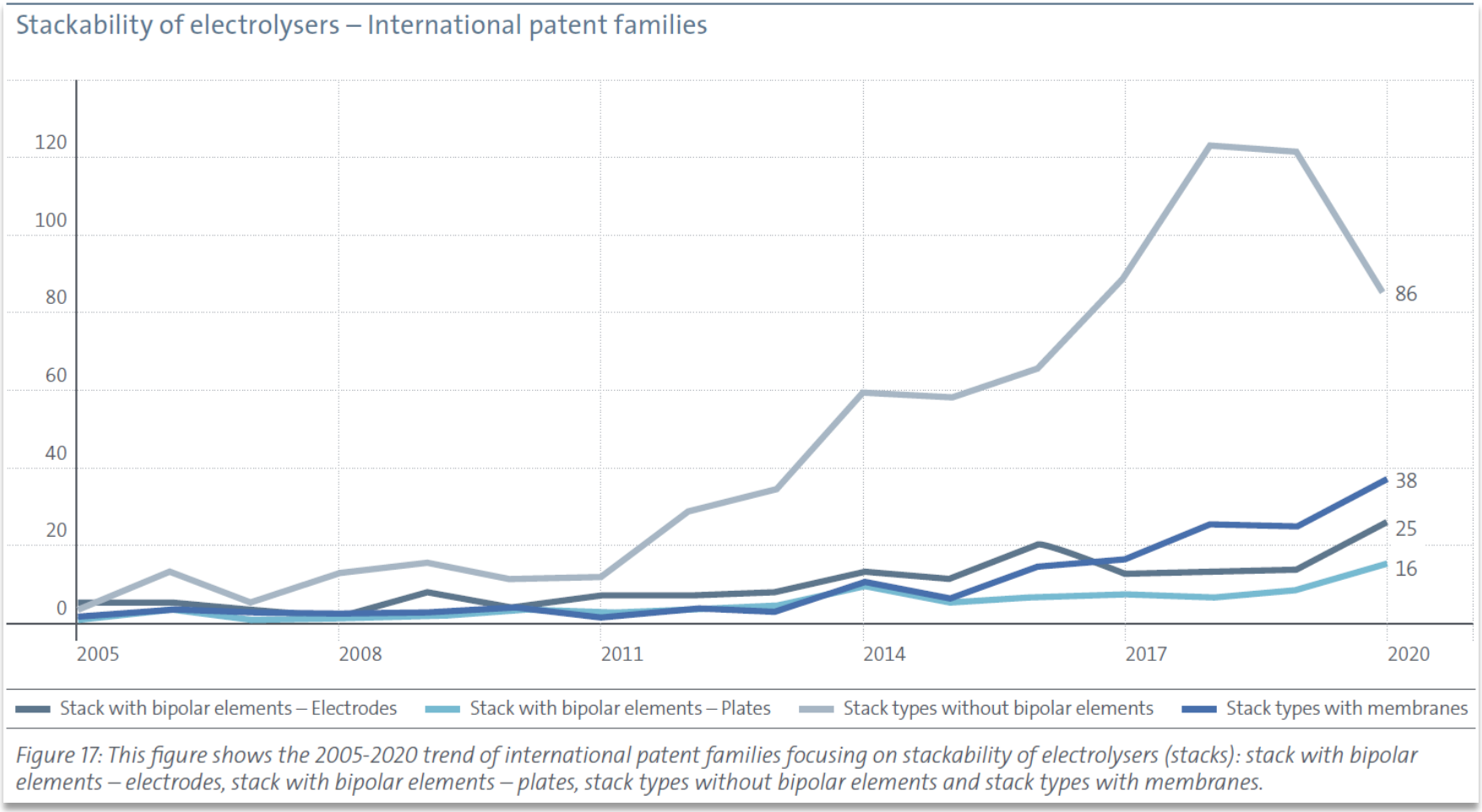

Figure 17: This figure shows the 2005-2020 trend of international patent families focusing on stackability of electrolysers (stacks): stack with bipolar elements – electrodes, stack with bipolar elements – plates, stack types without bipolar elements and stack types with membranes.

Stack types without bipolar elements

- **2005-2011:** IPFs stable
- **2012-2014**: first increase (IPFs tripled)
- **2015-2018**: second increase after stable 2015 (IPFs doubled)
- **2019-2020**: decrease (optimum balance compactness/space-saving and high space-time?)
- US lead up to **2014**, then JP becomes first

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Photoelectrolysis may make electrolysers more cost-competitive than being supplied by fossil-based electricity

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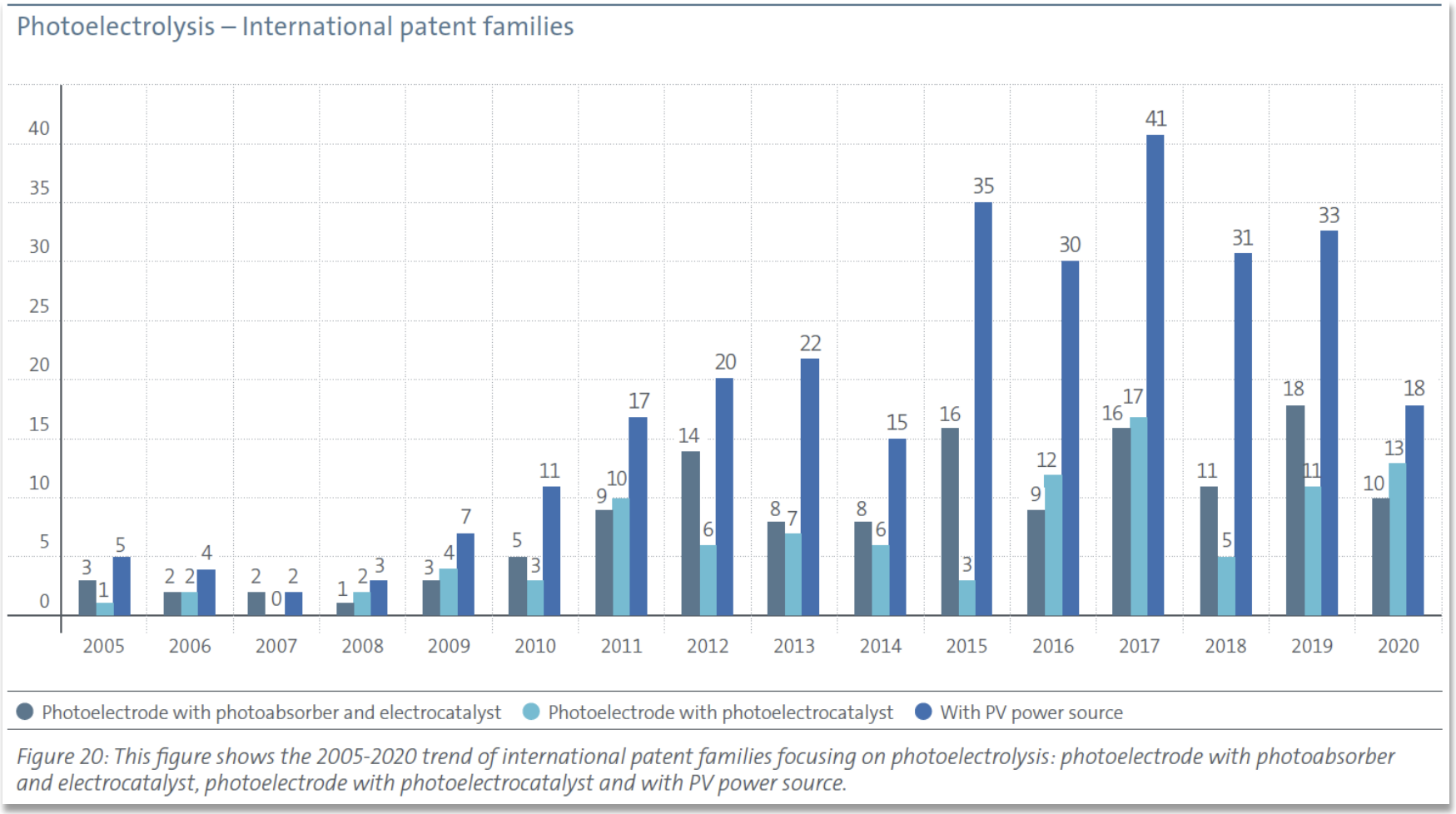

Figure 20: This figure shows the 2005-2020 trend of international patent families focusing on photoelectrolysis: photoelectrode with photoabsorber and electrocatalyst, photoelectrode with photoelectrocatalyst and with PV power source.

- From 2015 to **2017** major jump for **photoelectrolysis with PV** power source
- **JP** (40%, mostly 2015-2020) and **US** (16%, mostly 2004-2014) lead the three technology areas
- **Saudi Arabia**, **Netherlands** and **China** IPFs only in 2015-2020
- **Universities** in Saudi Arabia contribute to develop IPFs in the field of photoelectrolysis

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Electrolysers: key component in empowering the shift toward a hydrogen-based energy system

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New solutions to lower cost while raising technological efficiency and production capacity

→ **Renewable-based hydrogen technology enables decarbonization of energy-intensive industries and sectors**

1. Great attention is being paid to the search for **optimal operation conditions** and electrolyser structure to increase the **efficient production** of hydrogen
2. The surge in patents related to **non-noble metal electrocatalysts** indicates that R&D is moving towards finding new solutions and aims to mitigate the effect of **material scarcity**.
3. In searching for a simultaneous **increase in technological performance and durability**, patenting activity is moving towards **polymer (organic) separator membranes**.
4. To scale up the efficient and **economic production of hydrogen**, there is increased patenting activity with regard to the **stackability of electrolysers without bipolar elements** and, more recently, with membranes.
5. Many universities worldwide are focusing on the development of new inventions to split water using (sun)light as the energy source: **photoelectrolysis** is the **emerging patenting area**.

Online dashboard

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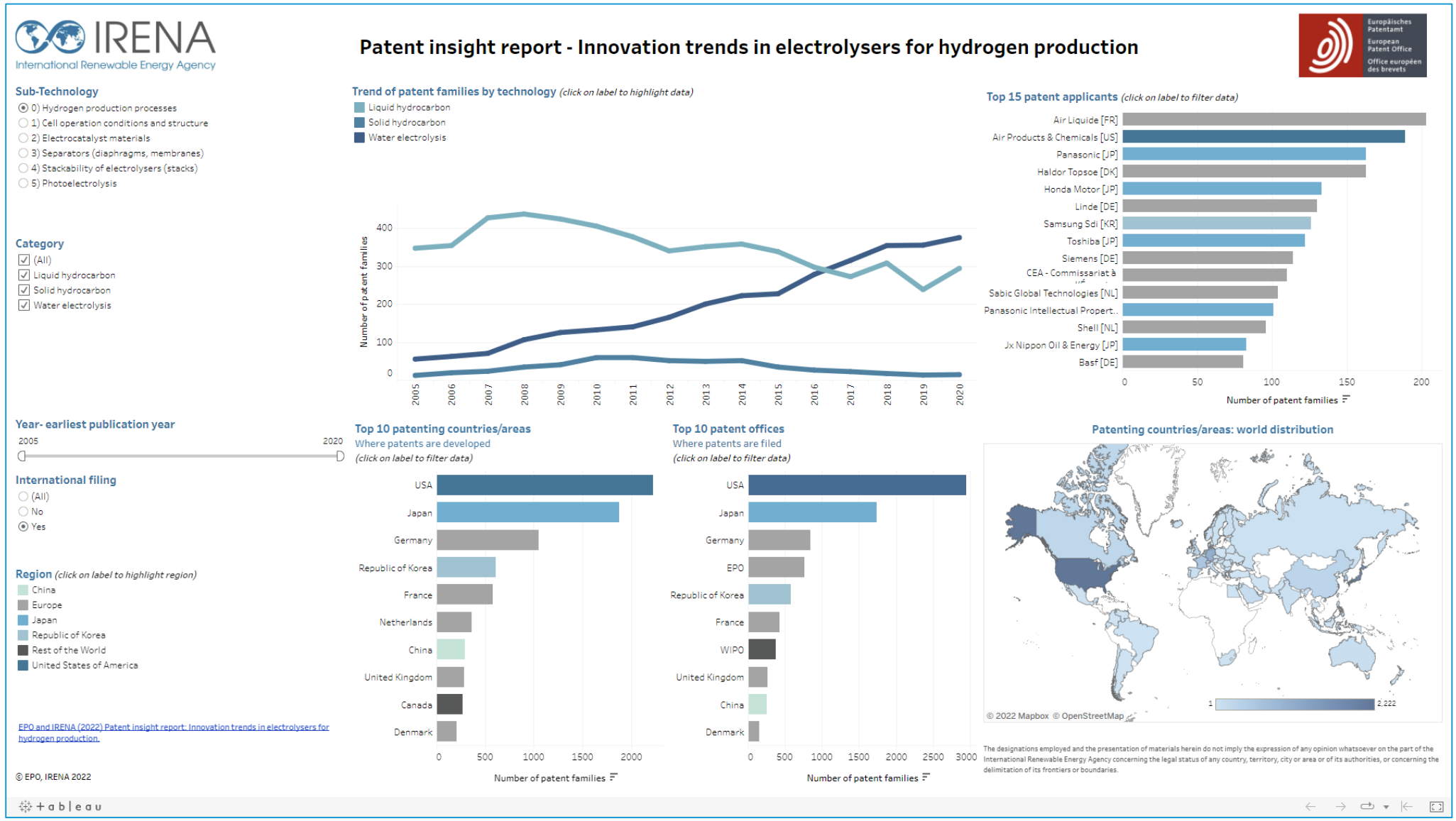

https://public.tableau.com/views/IRENA_Electrolysers_Patents_Insights/Electrolysers_patent_insight?:showVizHome=no&embed=yes

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Q & A
10 min

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