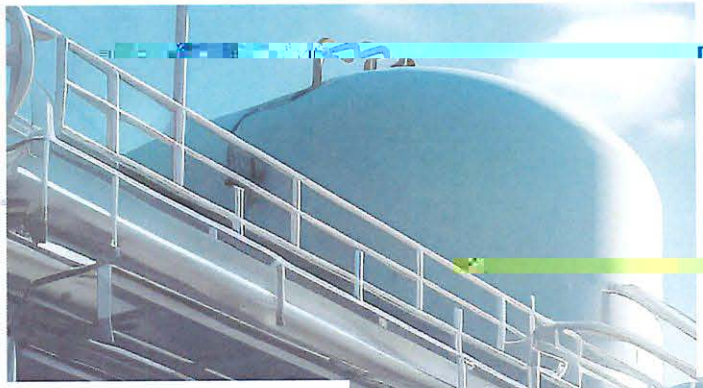

Date: November 15, 2023

Albus Zhou

Name: Albus Zhou

Title: Executive Director

For and on behalf of

Frost & Sullivan (Beijing) Inc., Shanghai Branch Co.

Confidential

Global and China Hydrogen Industry

Independent Market Research

To: REFIRE

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弗若斯特沙利文(北京)咨询有限公司上海分公司

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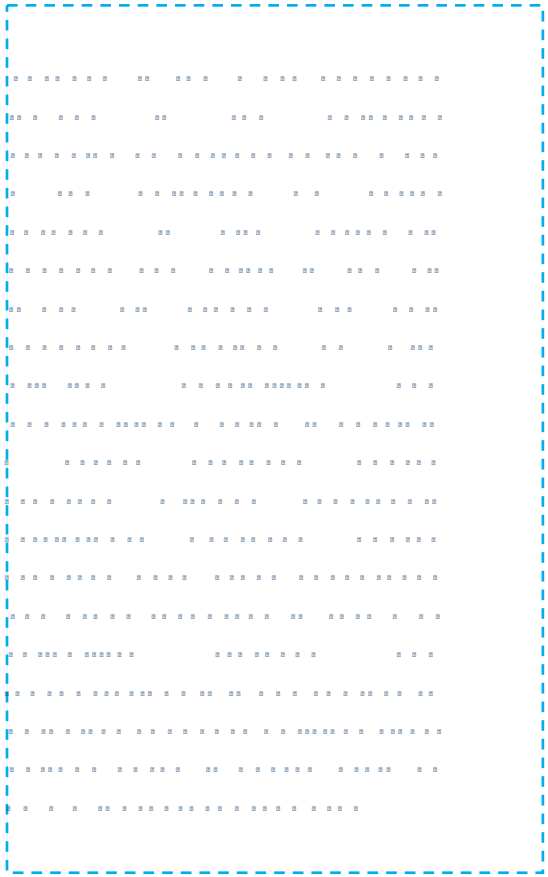

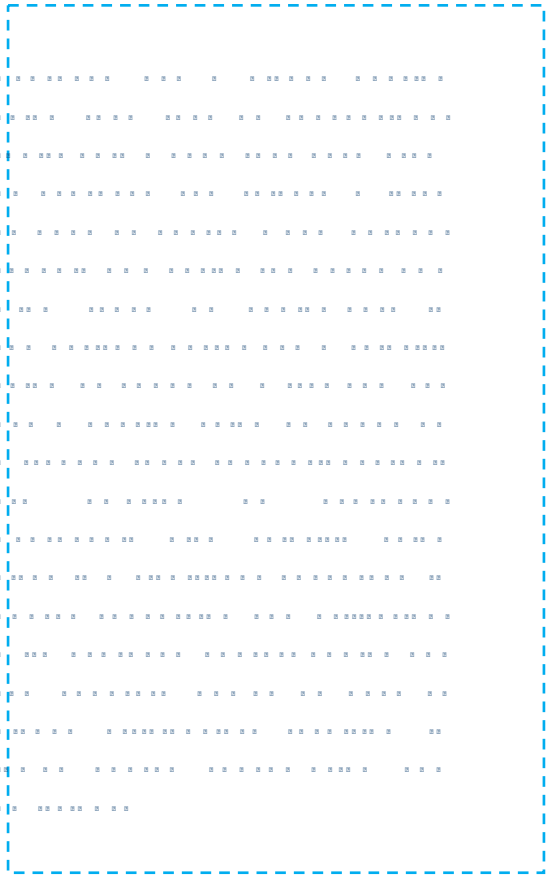

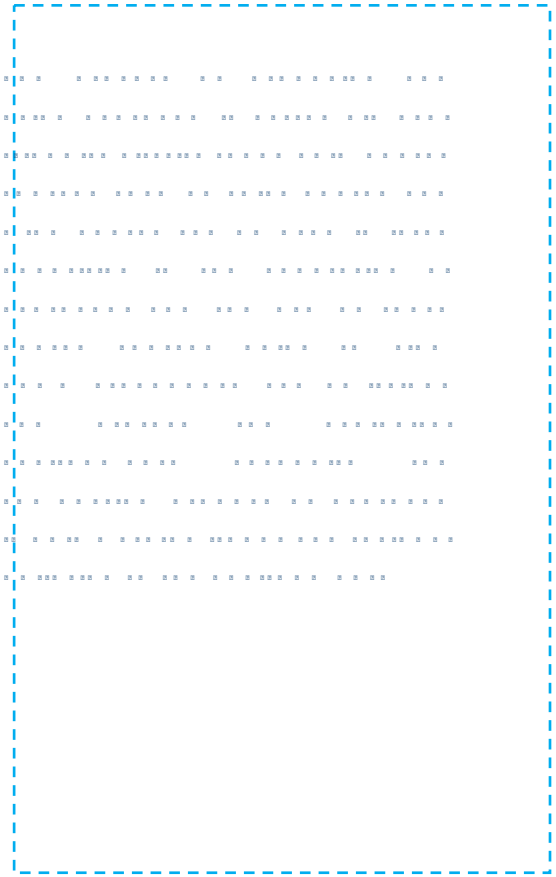

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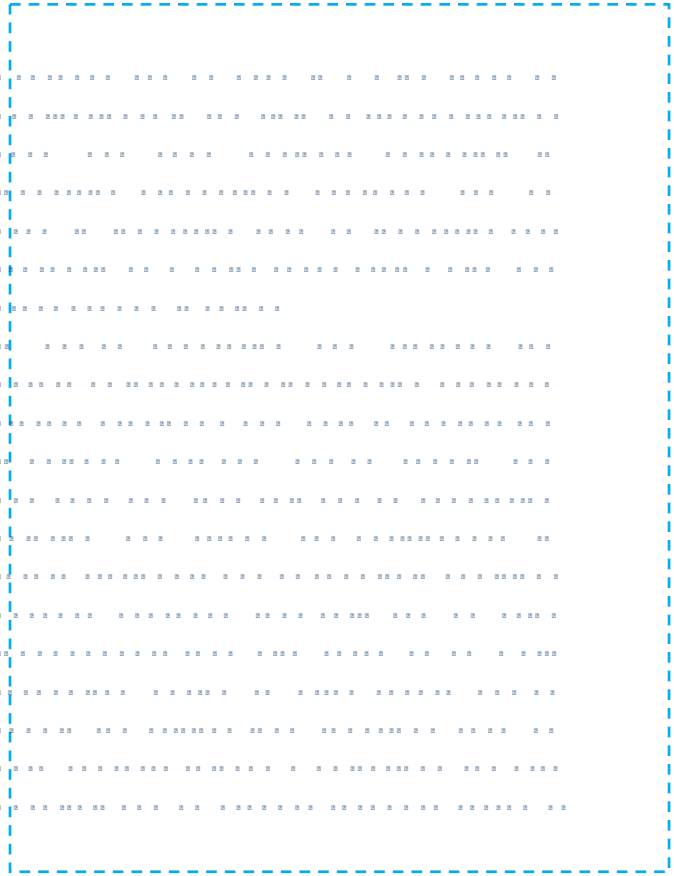

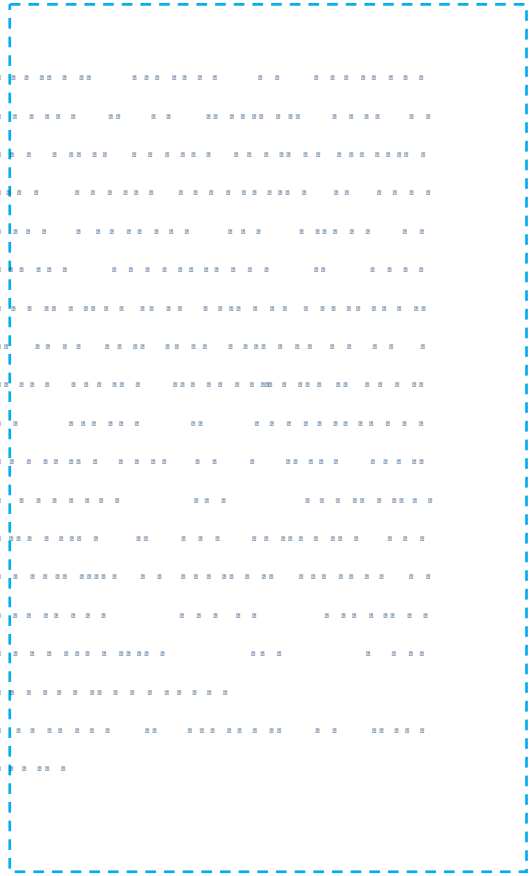

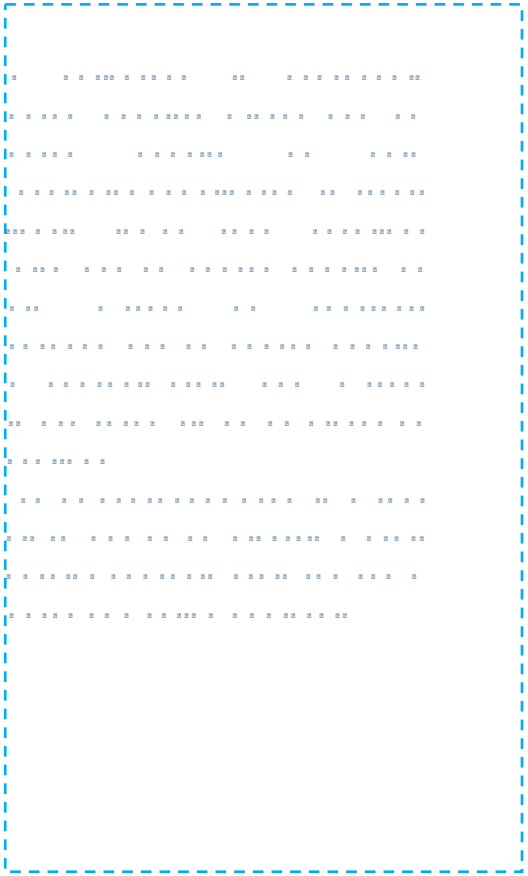

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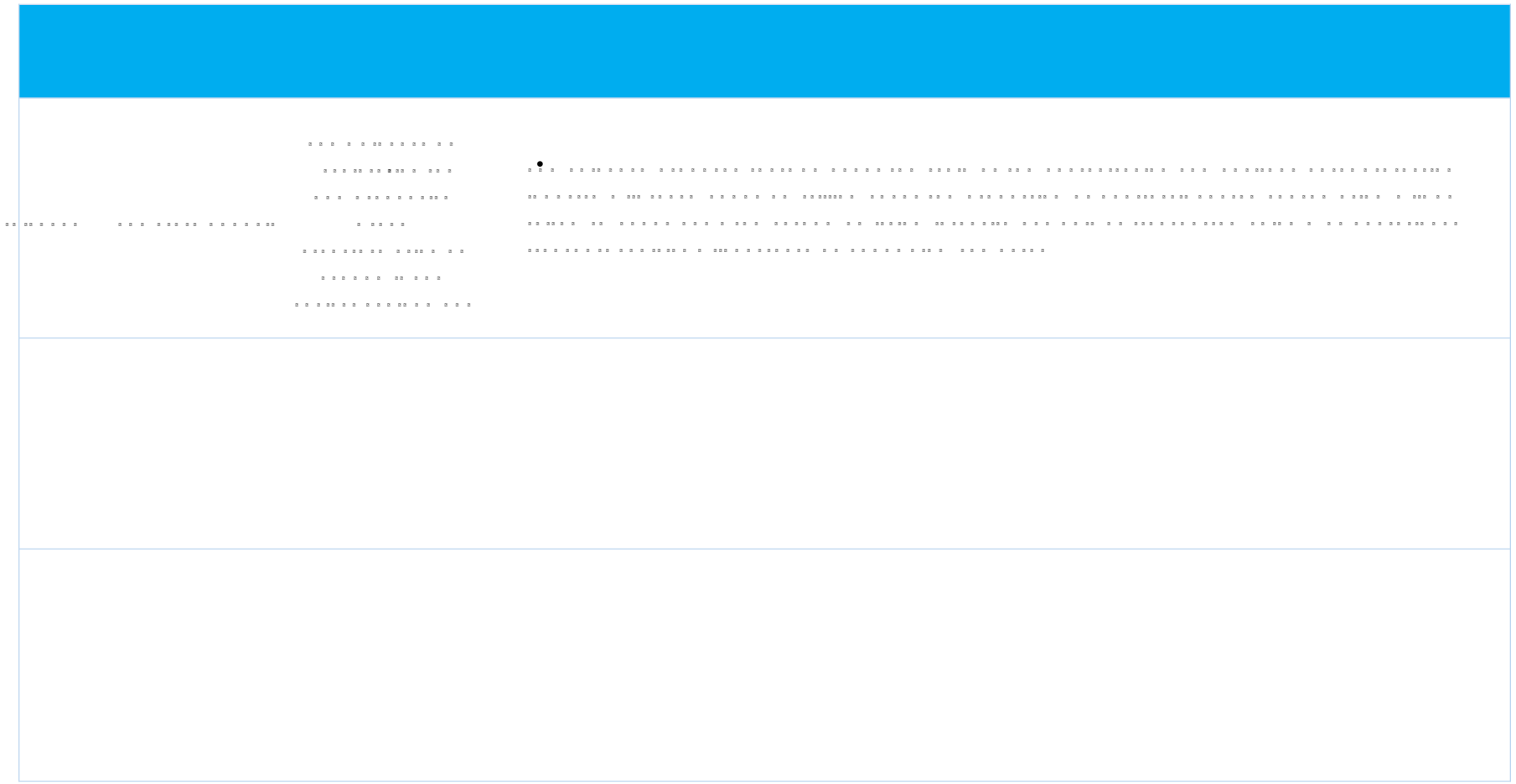

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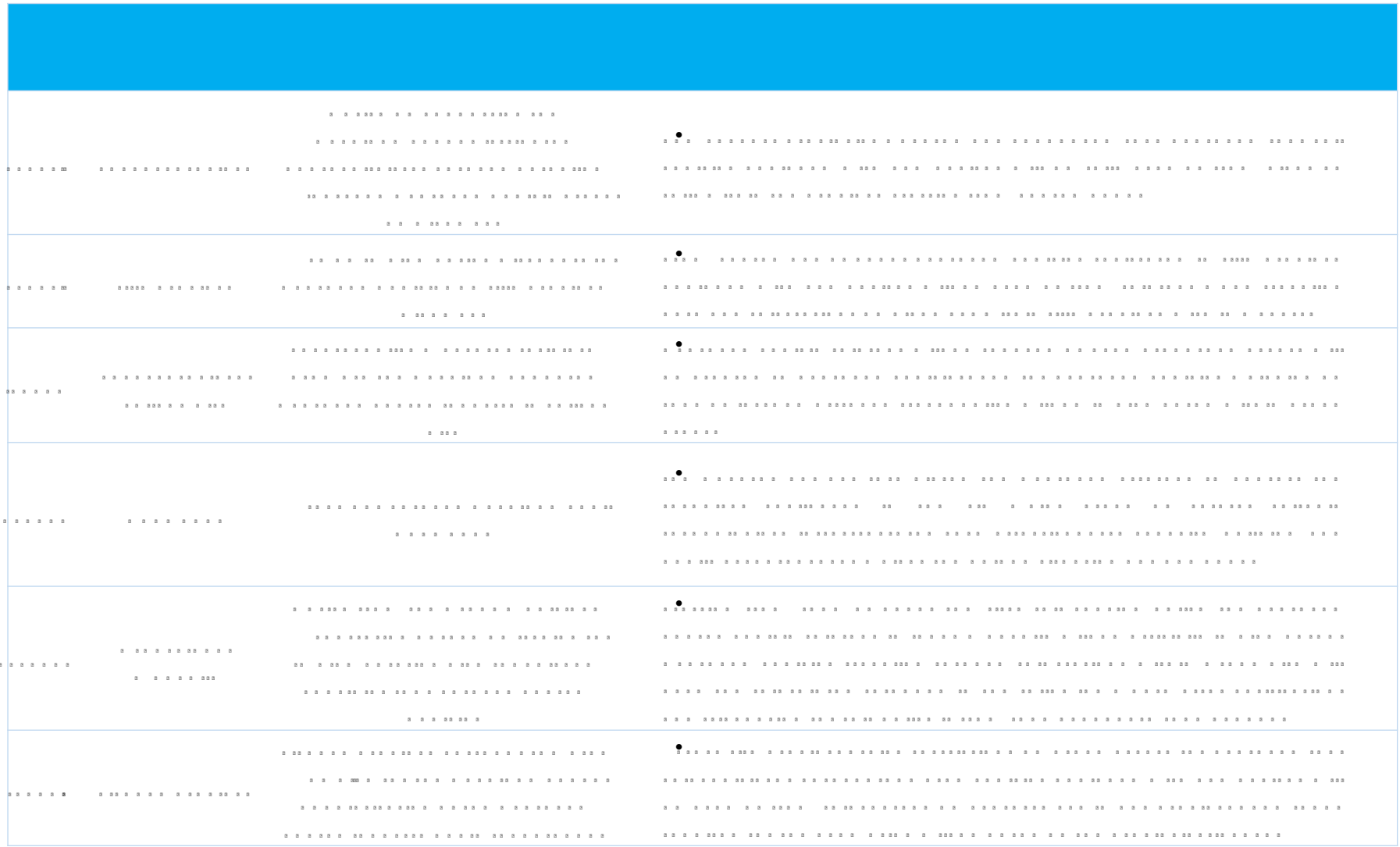

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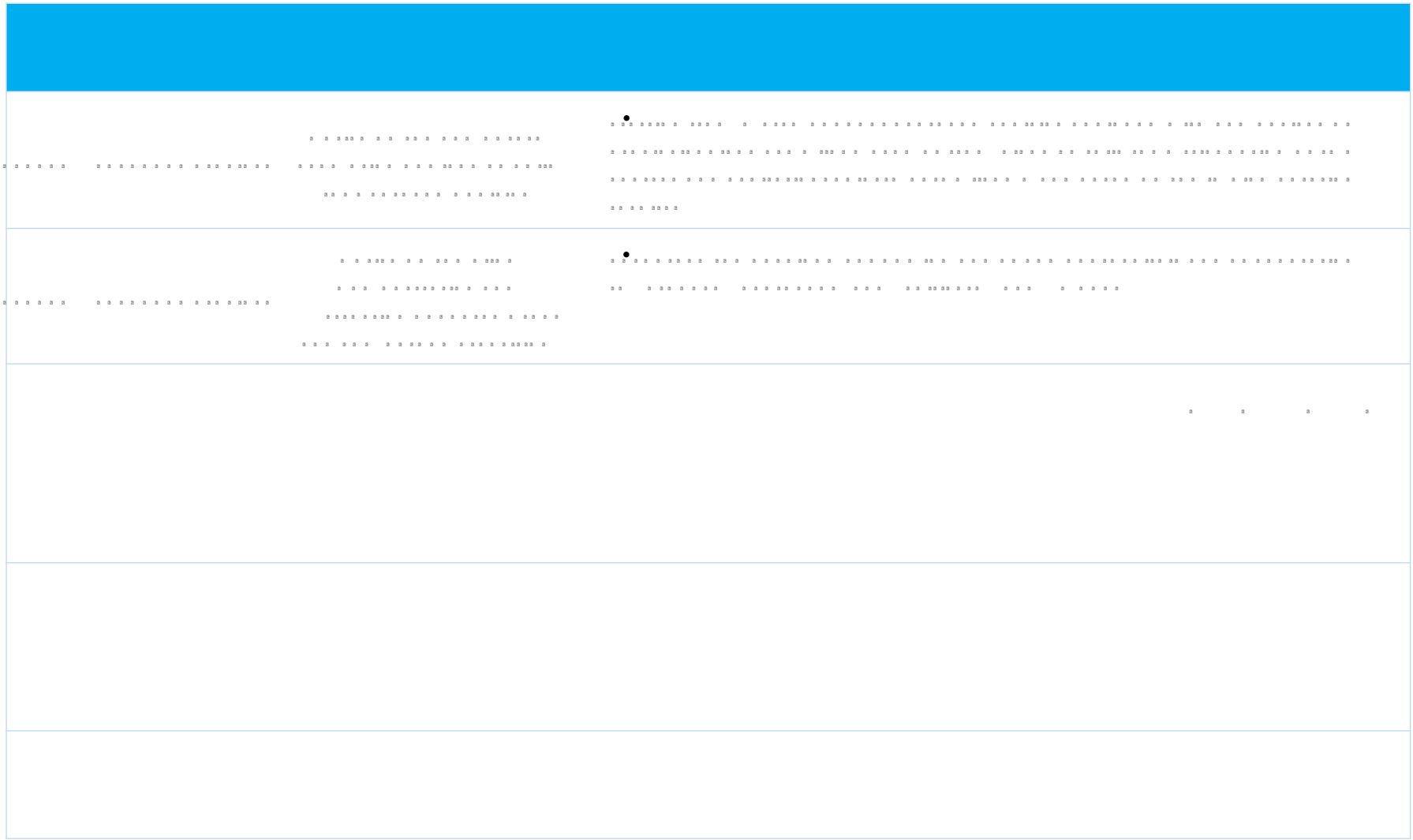

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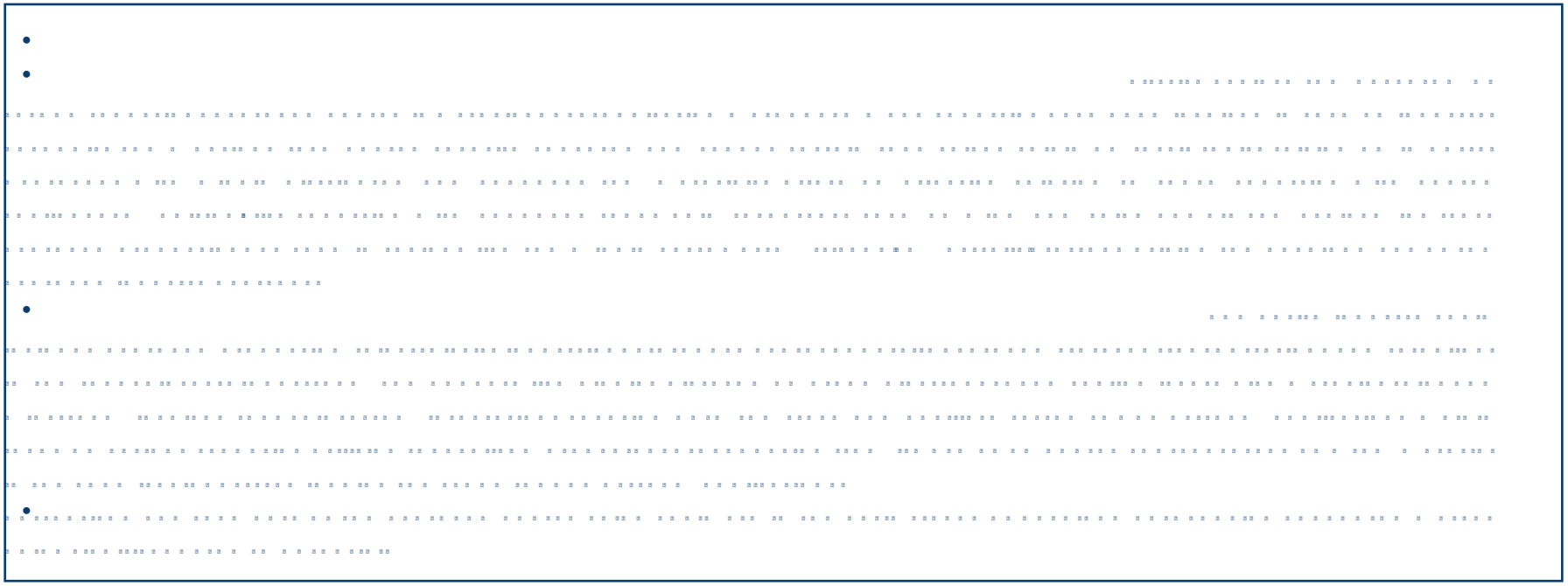

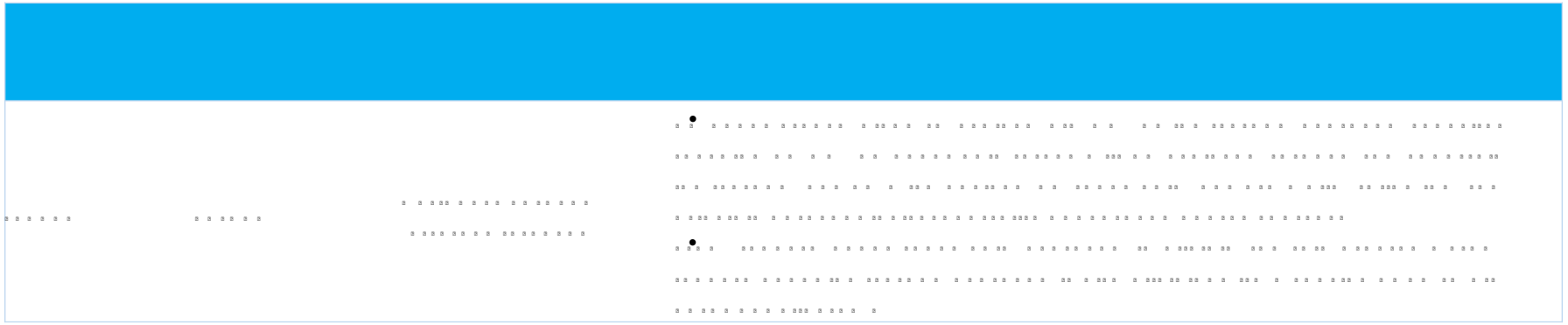

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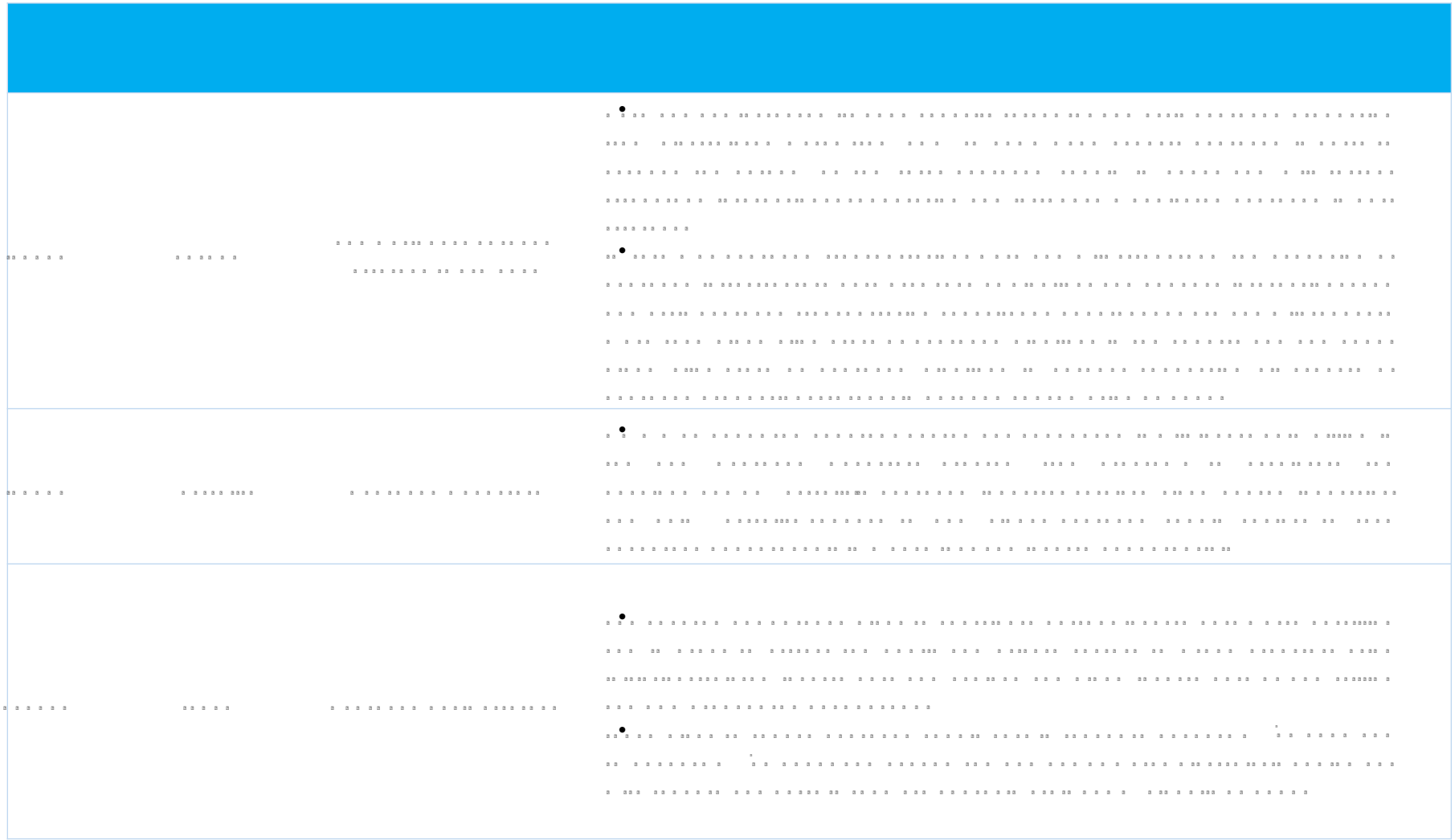

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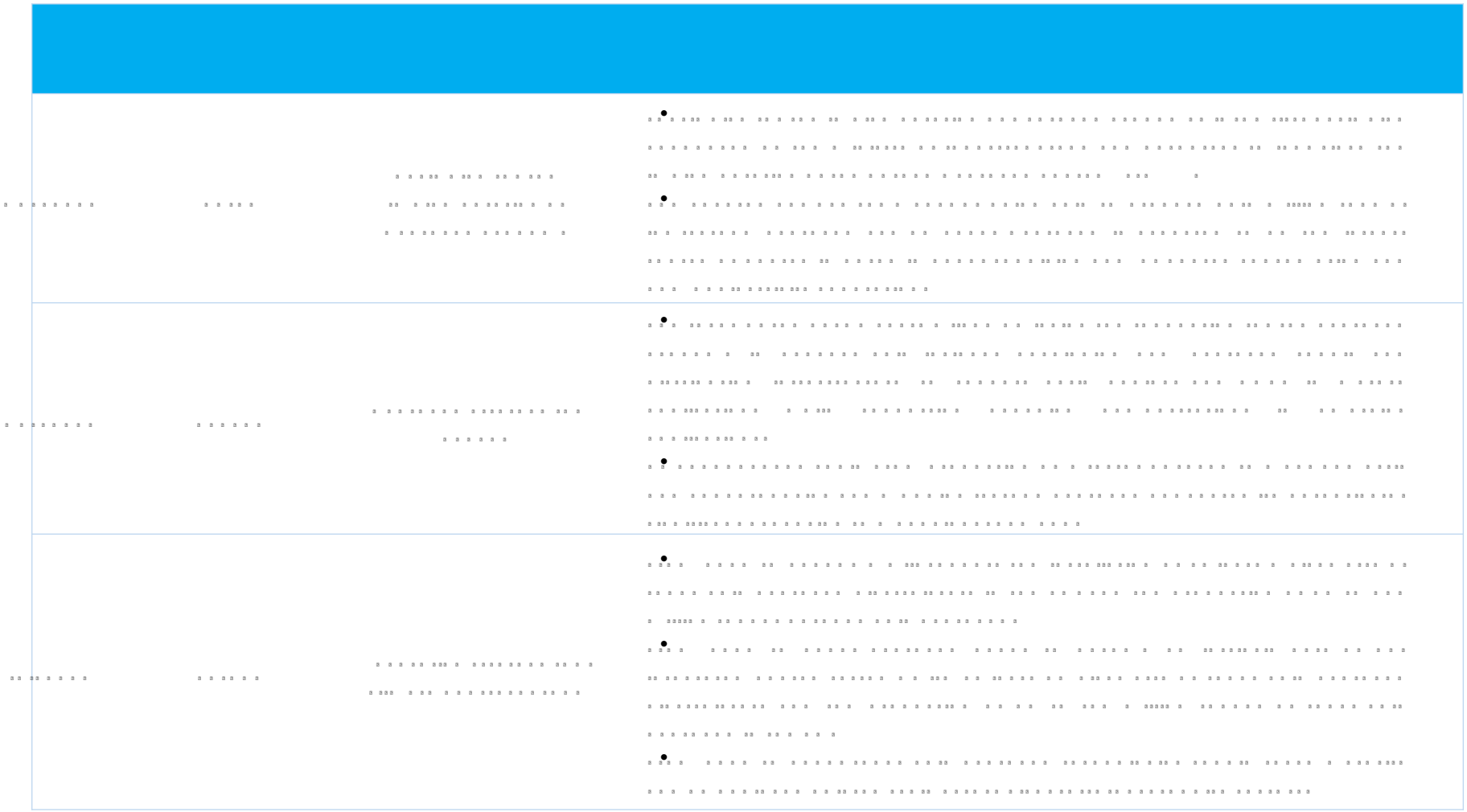

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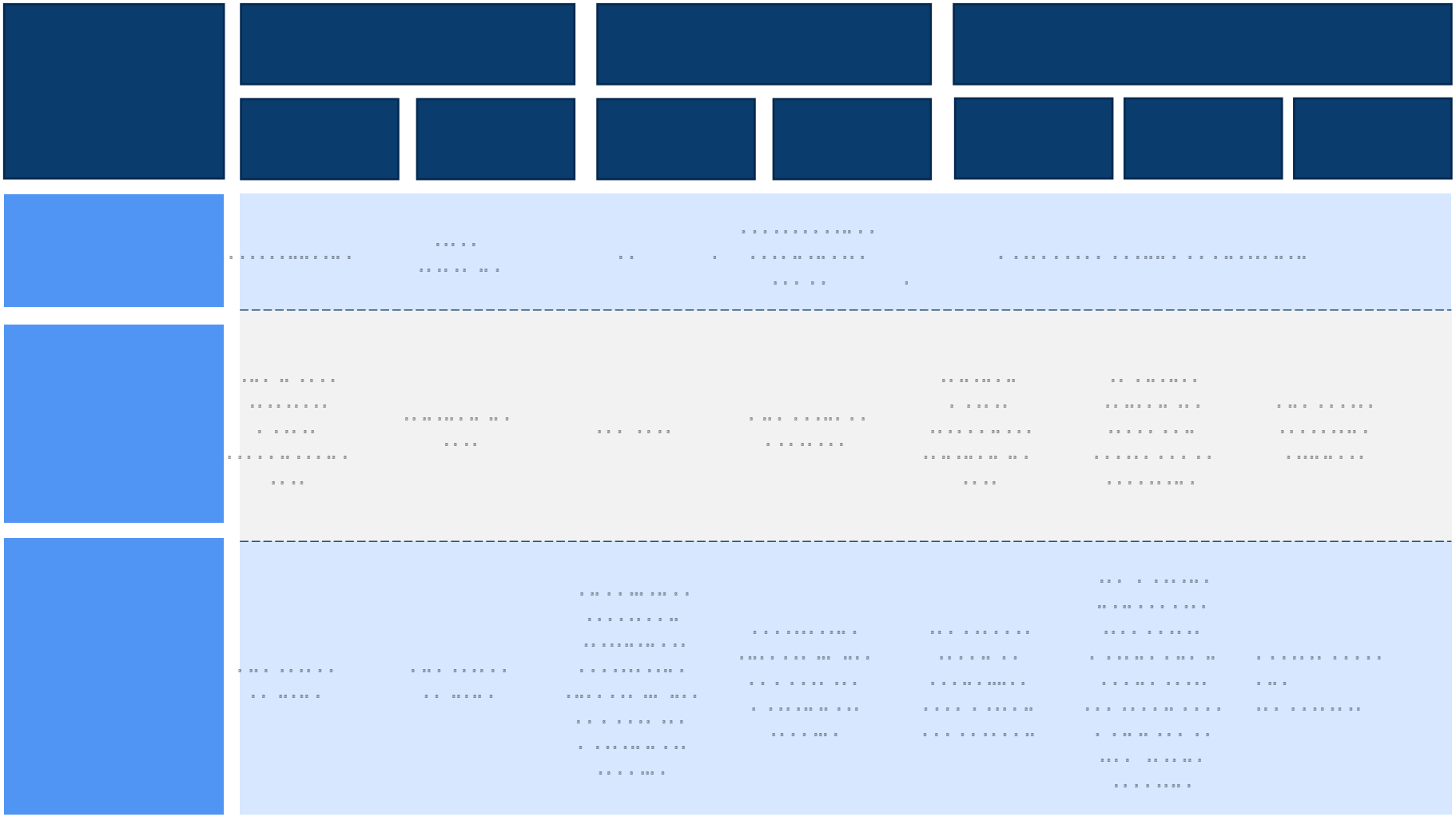

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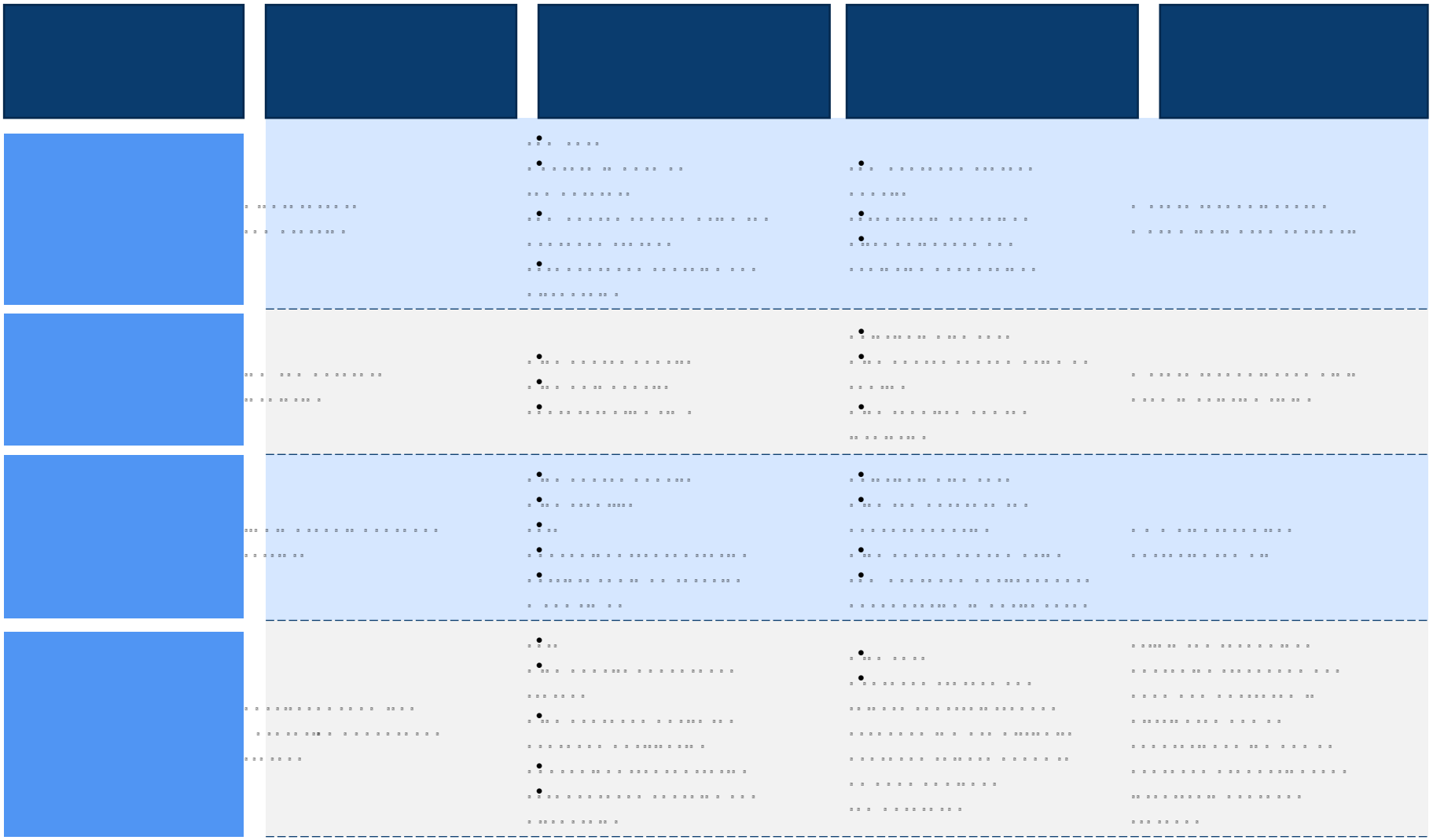

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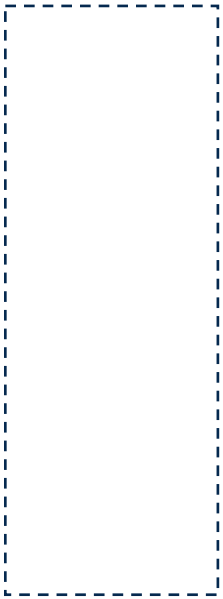

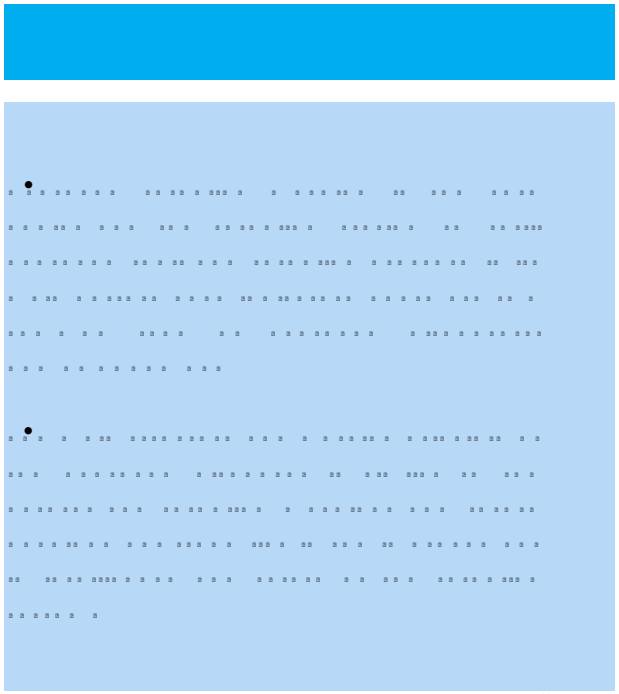

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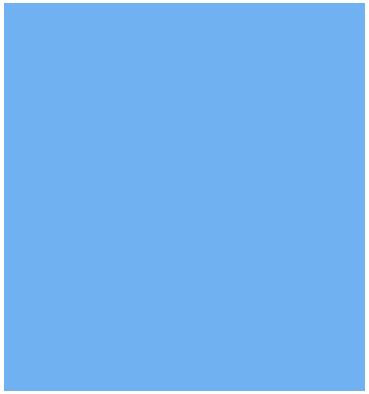

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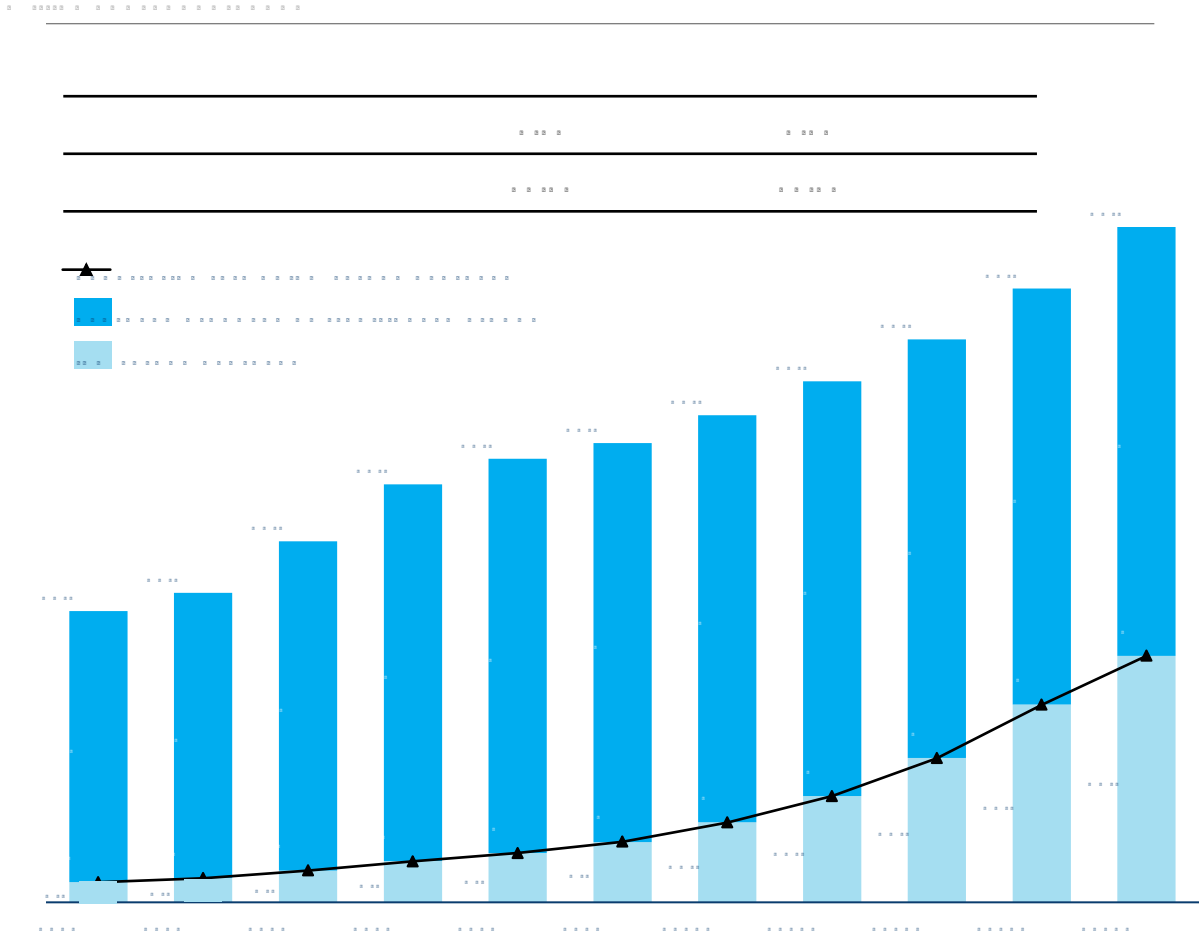
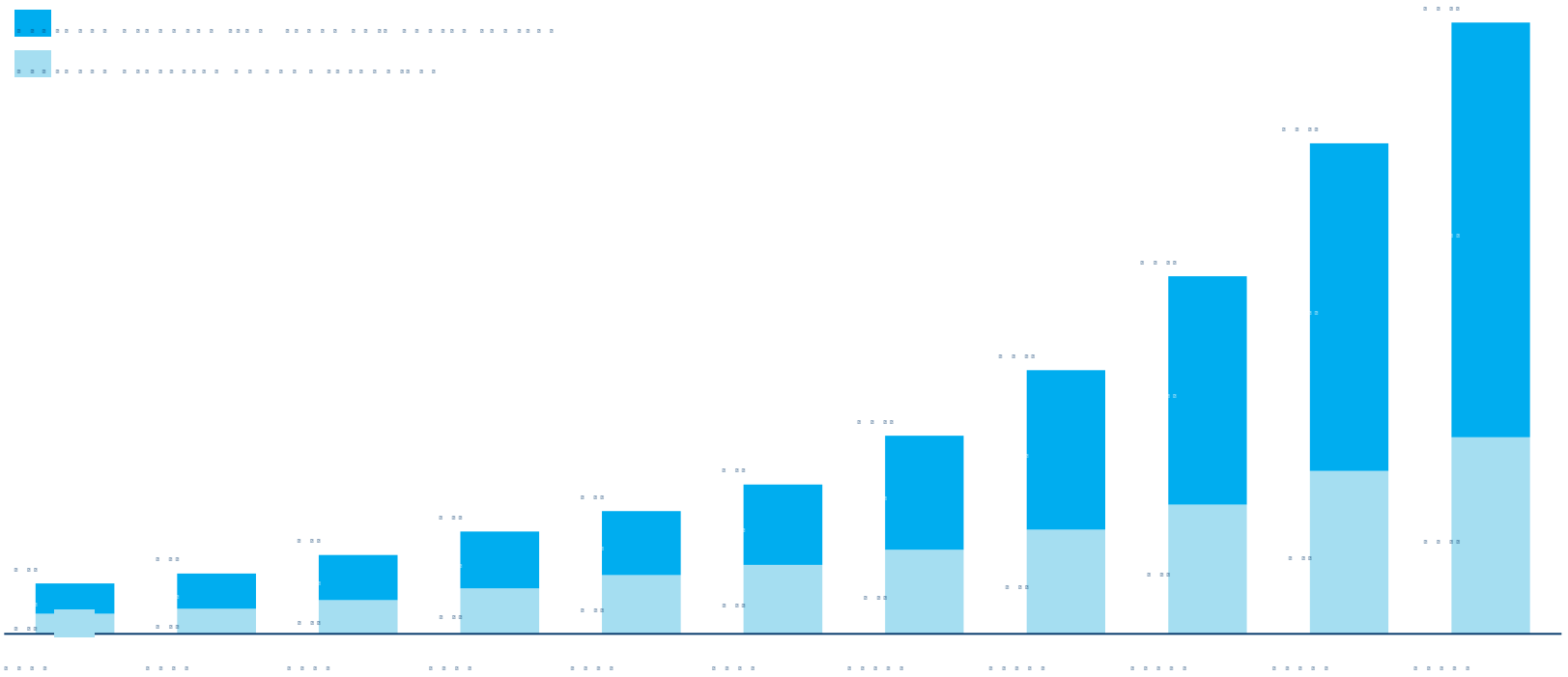


Note: The low-carbon hydrogen refers to hydrogen produced from renewable energy sources and hydrogen processed by CCUS technology.

Source: IEA, Hydrogen Council, Frost & Sullivan



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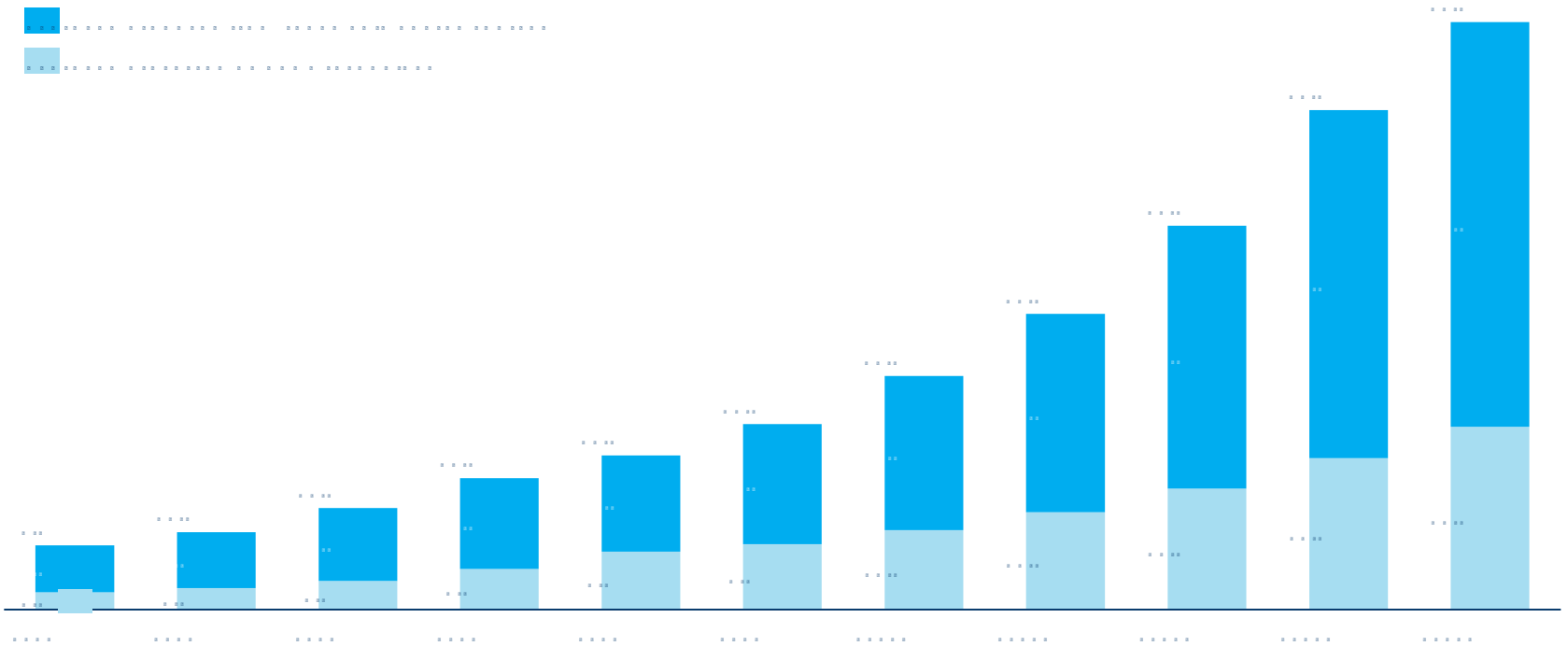
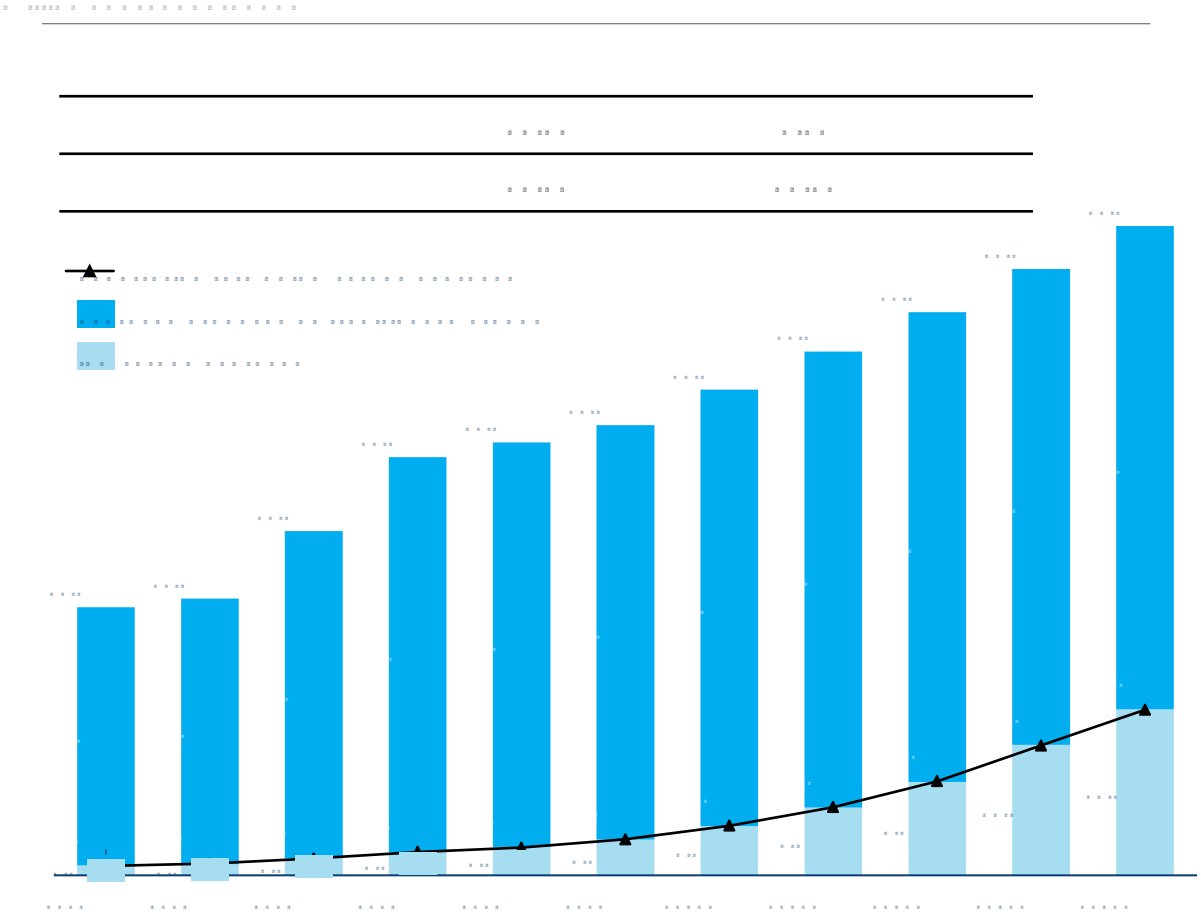


Source: IEA, Hydrogen Council, Frost & Sullivan



Note: 1) The market size of China's hydrogen consumption, by volume, refers to the apparent consumption volume of hydrogen in China. (apparent consumption = current year imports - current year exports + current year production);
2) The low-carbon hydrogen refers to hydrogen produced from renewable energy sources and hydrogen processed by CCUS technology.

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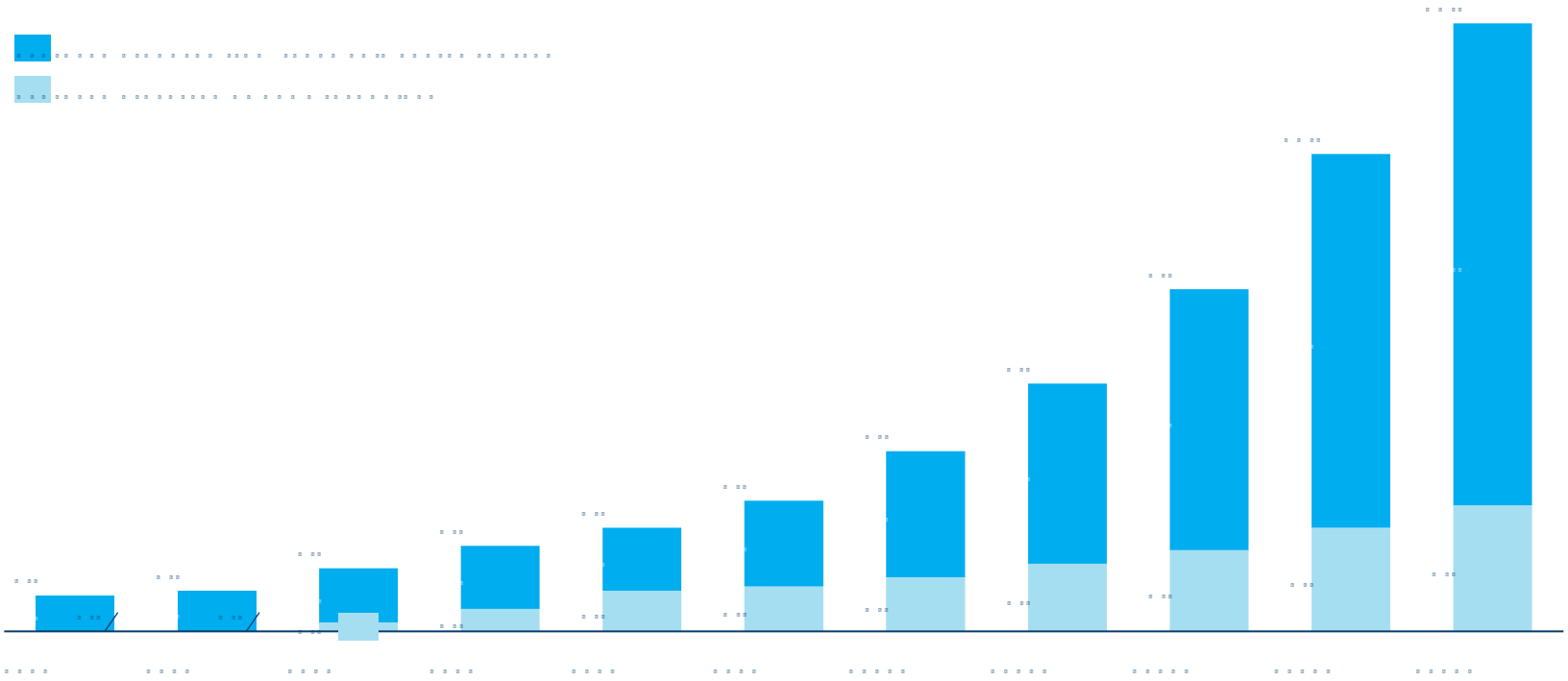
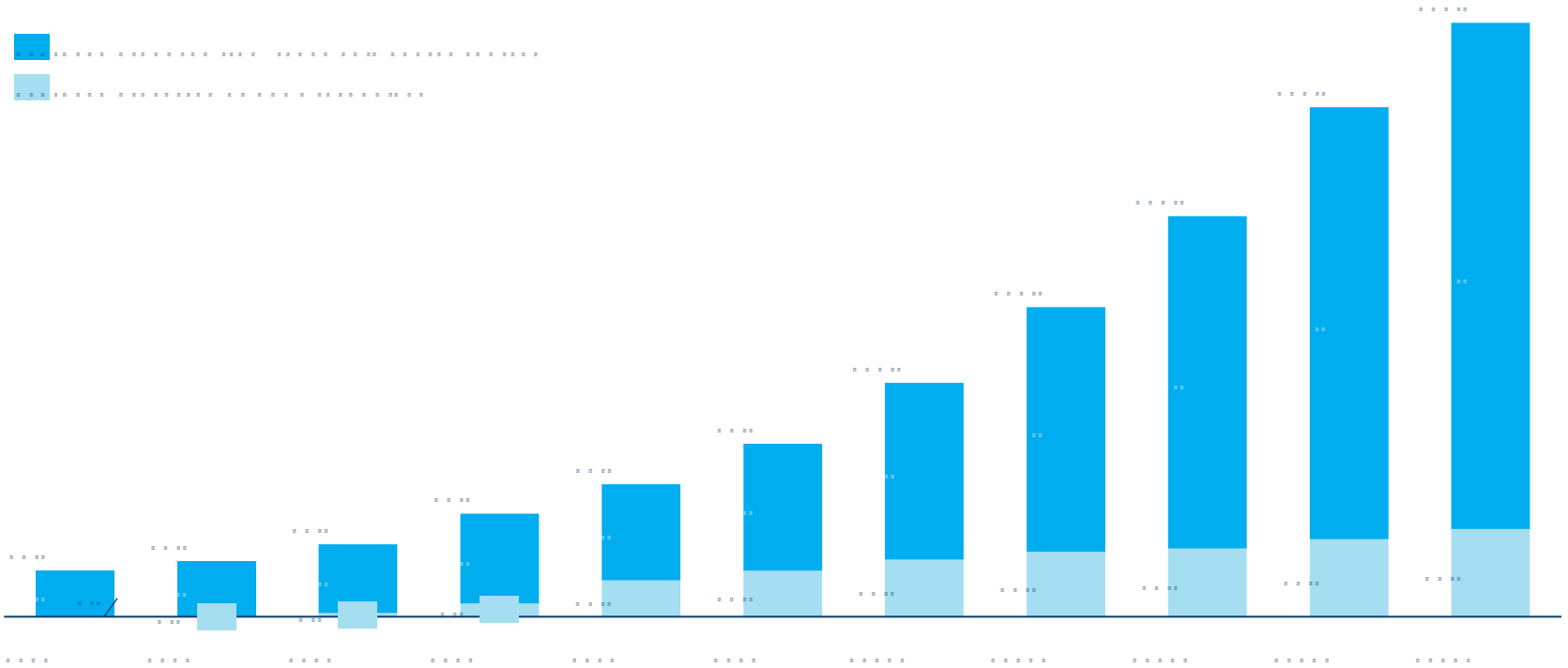
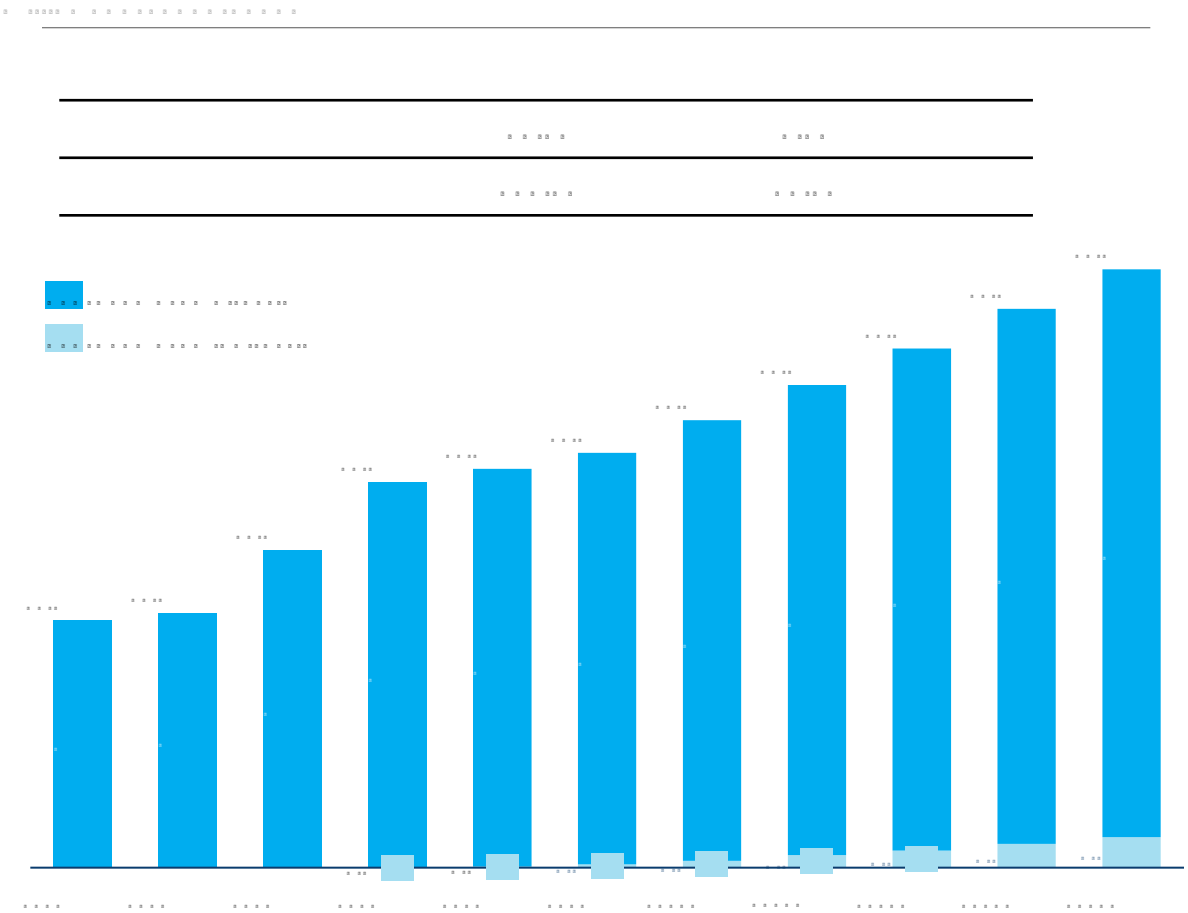
Source: China National Coal Association (CNCA), National Alliance of Hydrogen and Fuel Cell (CHA), Frost & Sullivan



Source: IEA, Hydrogen Council, Frost & Sullivan

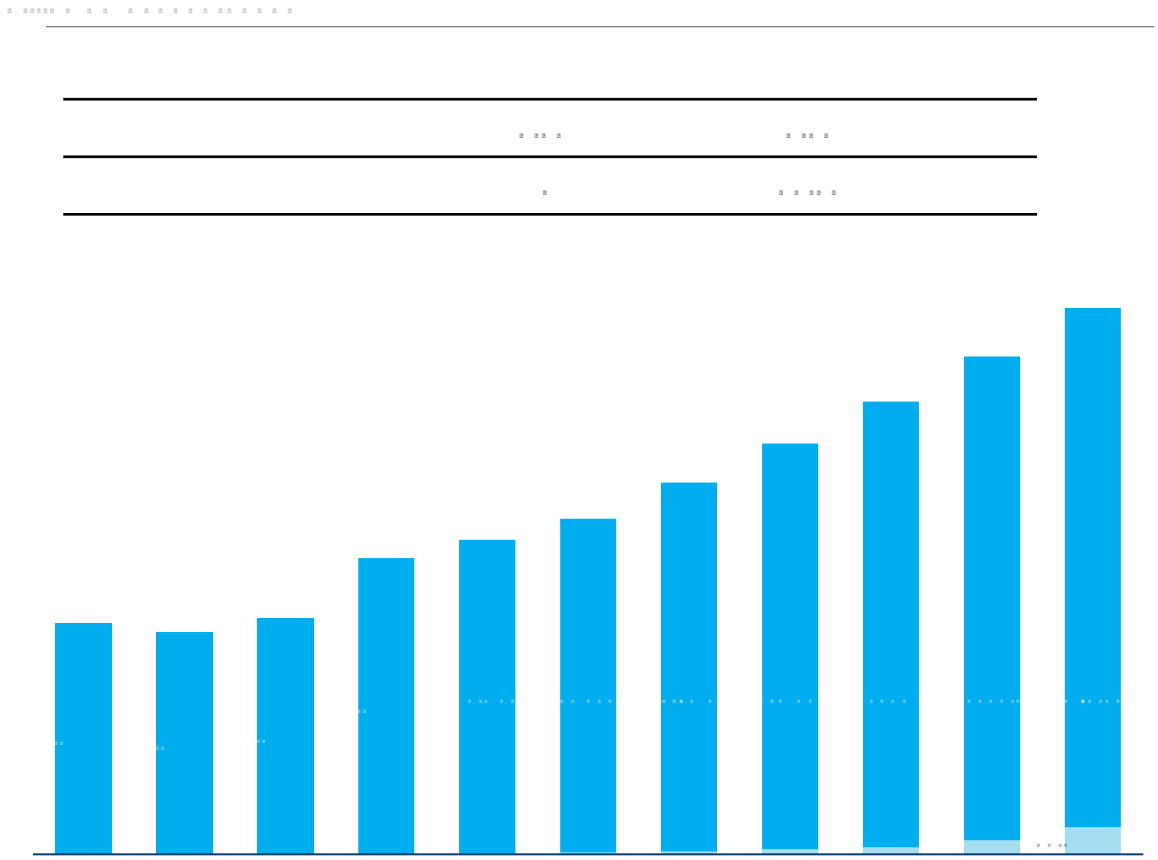


Source: IEA, Hydrogen Council, Frost & Sullivan



Note: Hydrogen could be directly used in the chemical industry, iron industry, and so on; hydrogen can be indirectly used in the transportation industry, electricity generation, construction industry, etc., through fuel cell systems.

Source: China Hydrogen Alliance, Frost & Sullivan



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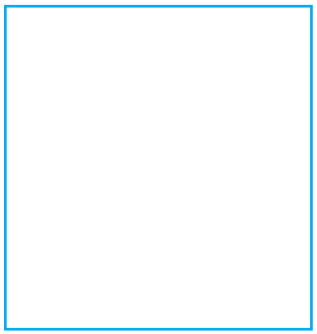
Source: China Hydrogen Alliance, Frost & Sullivan



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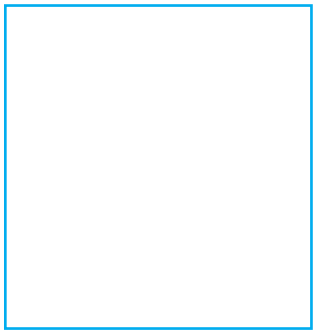

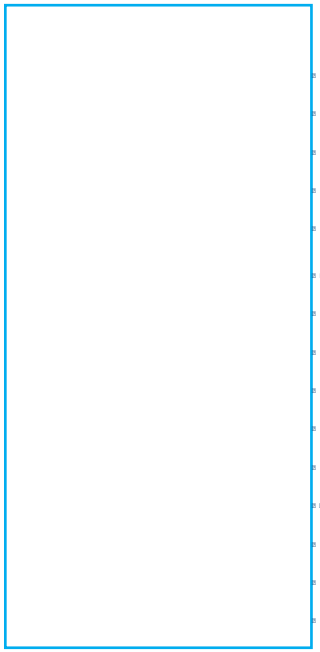

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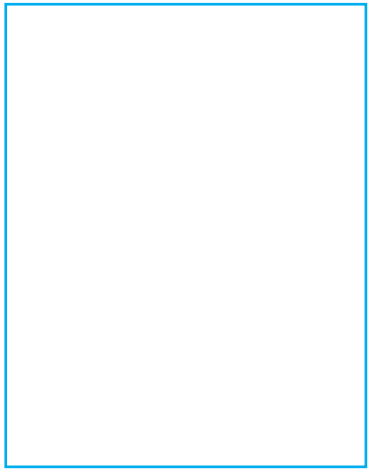

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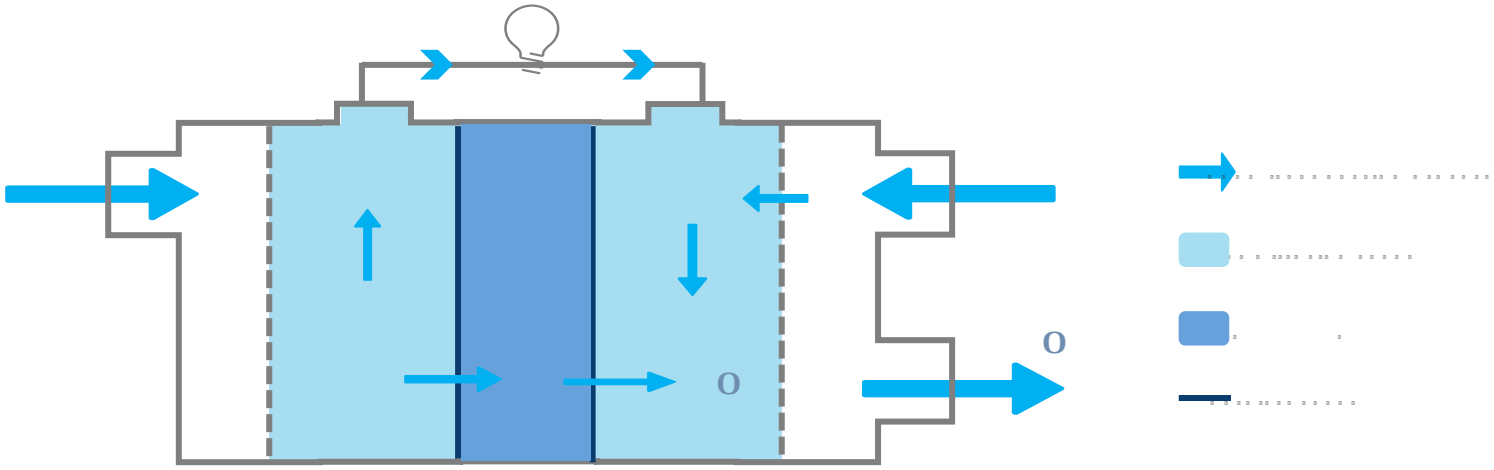

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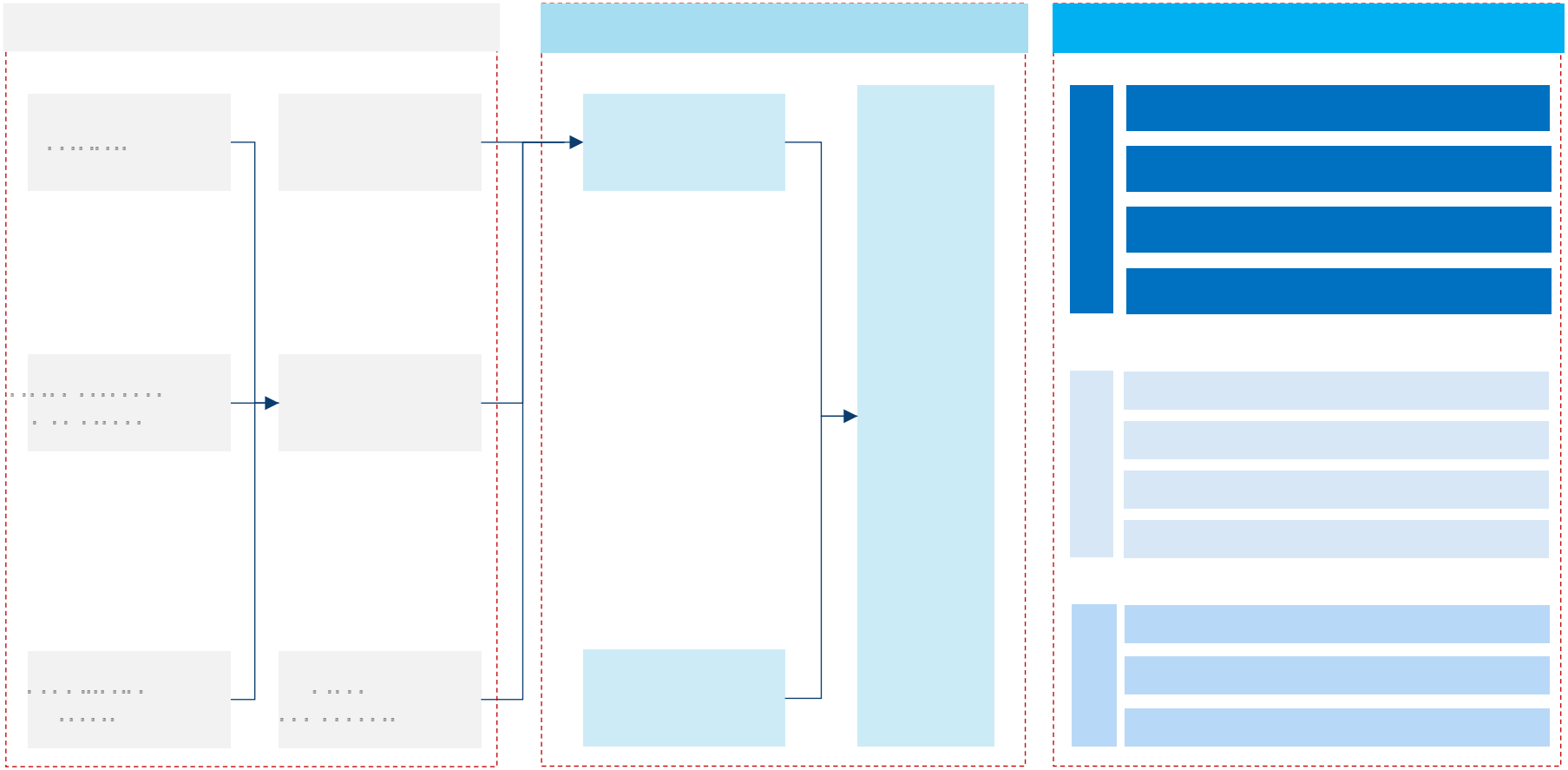

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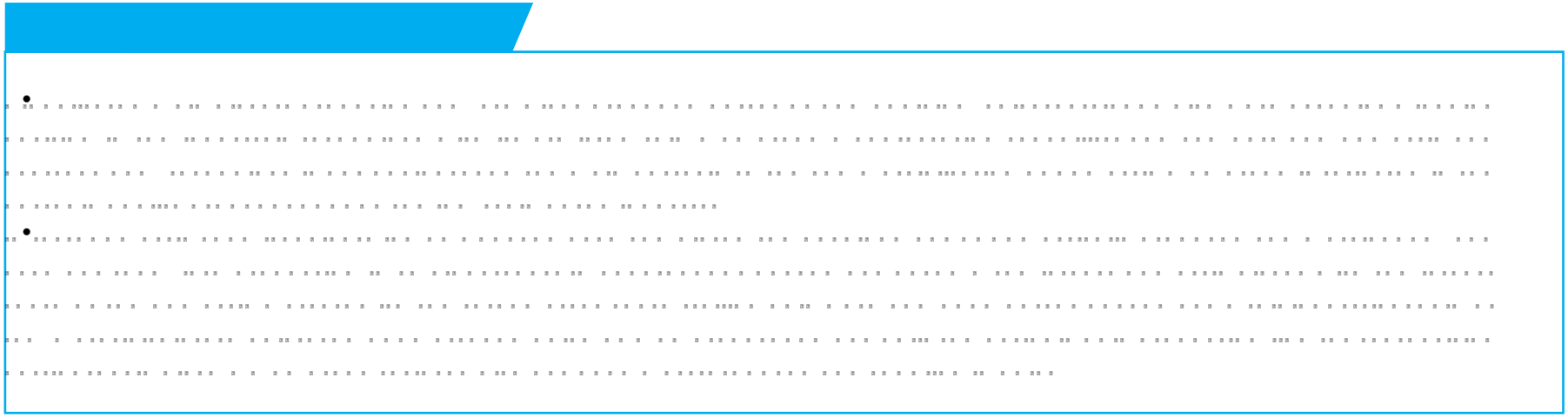
Source: Frost & Sullivan



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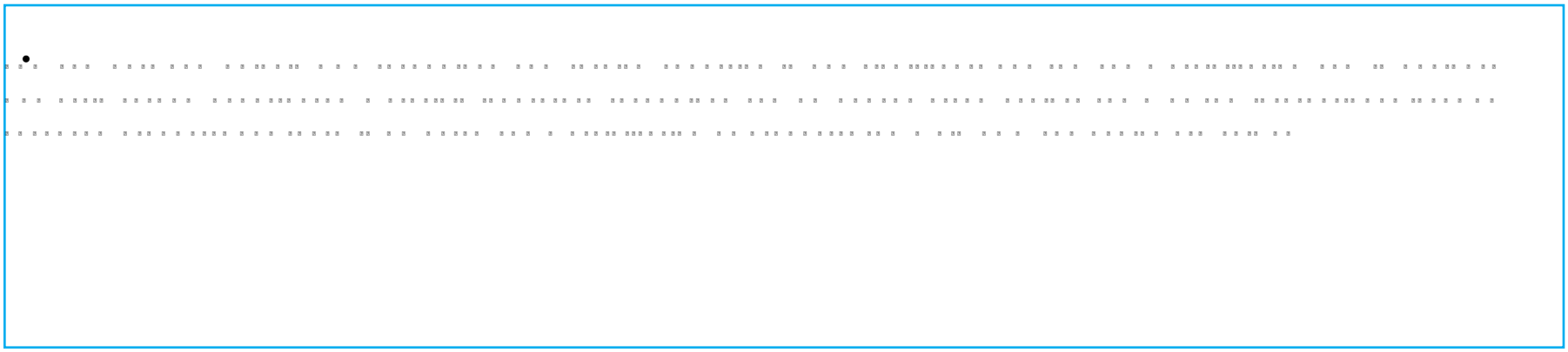

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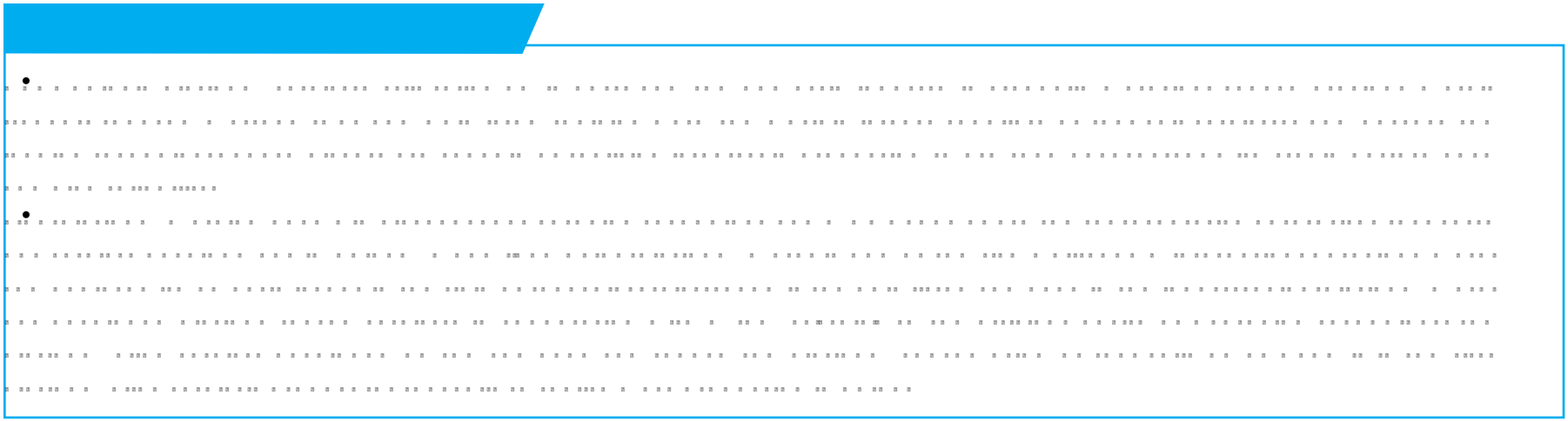

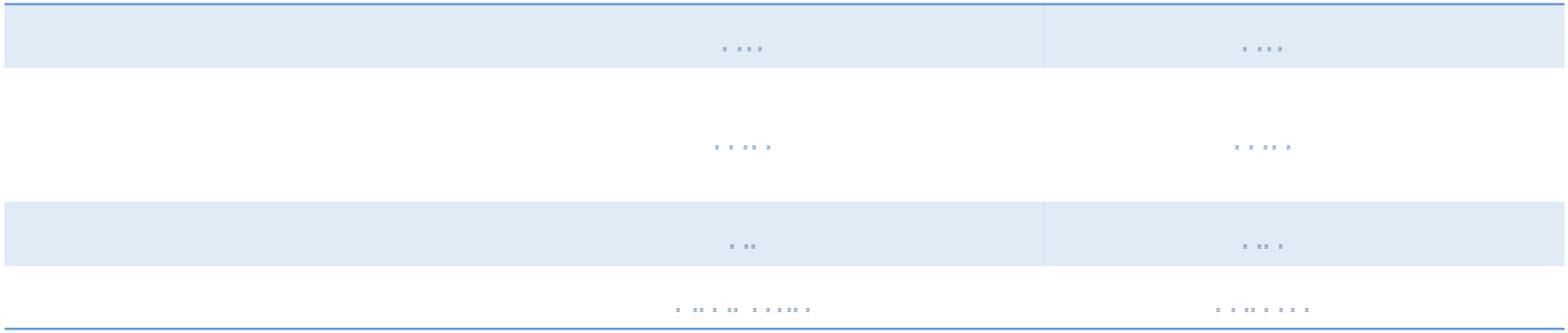

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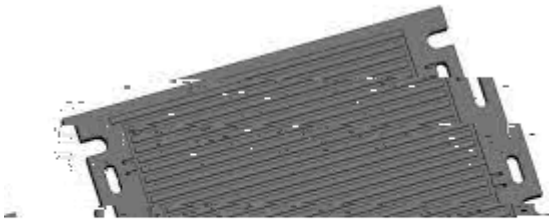

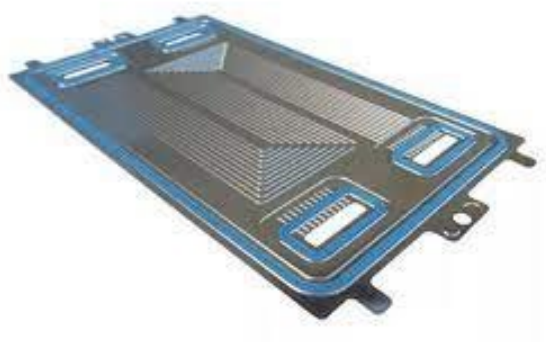

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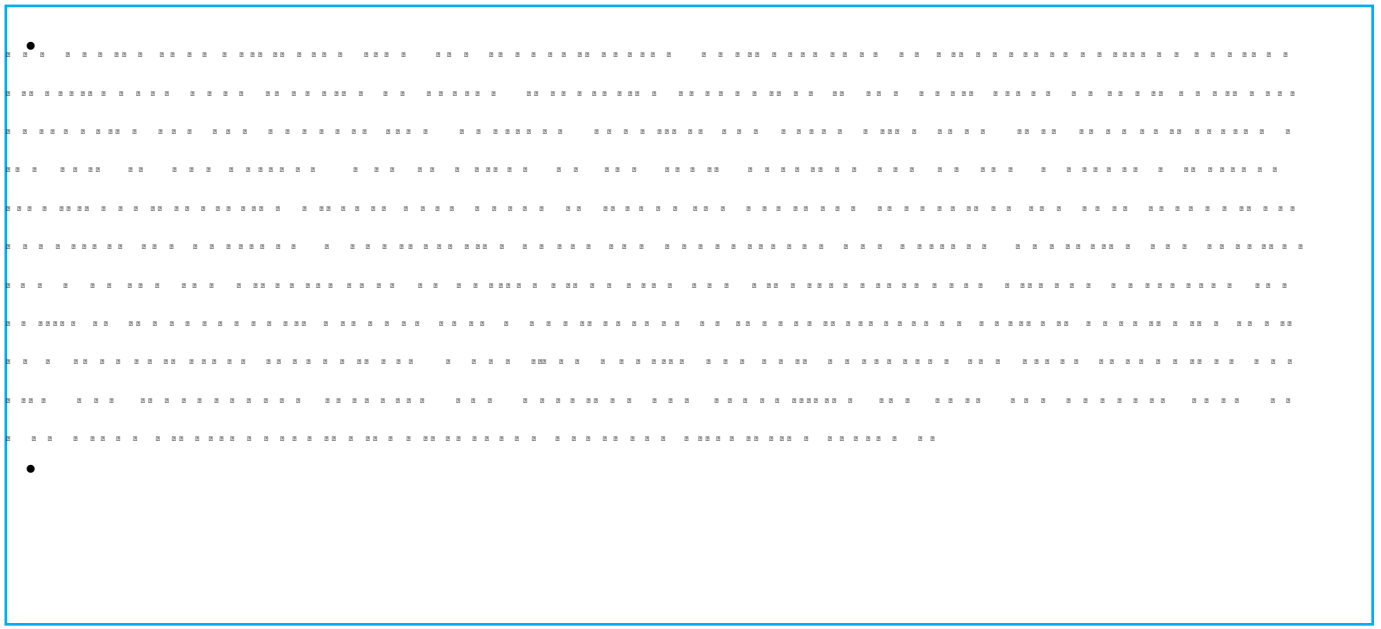

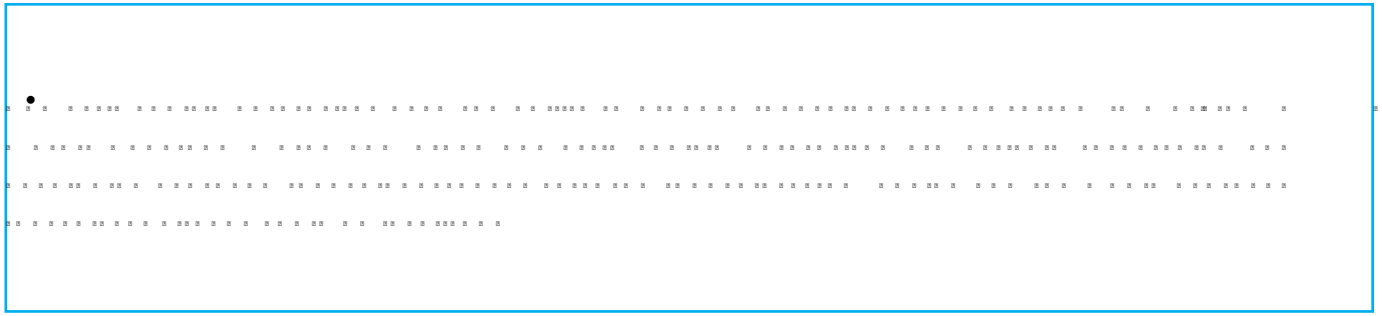

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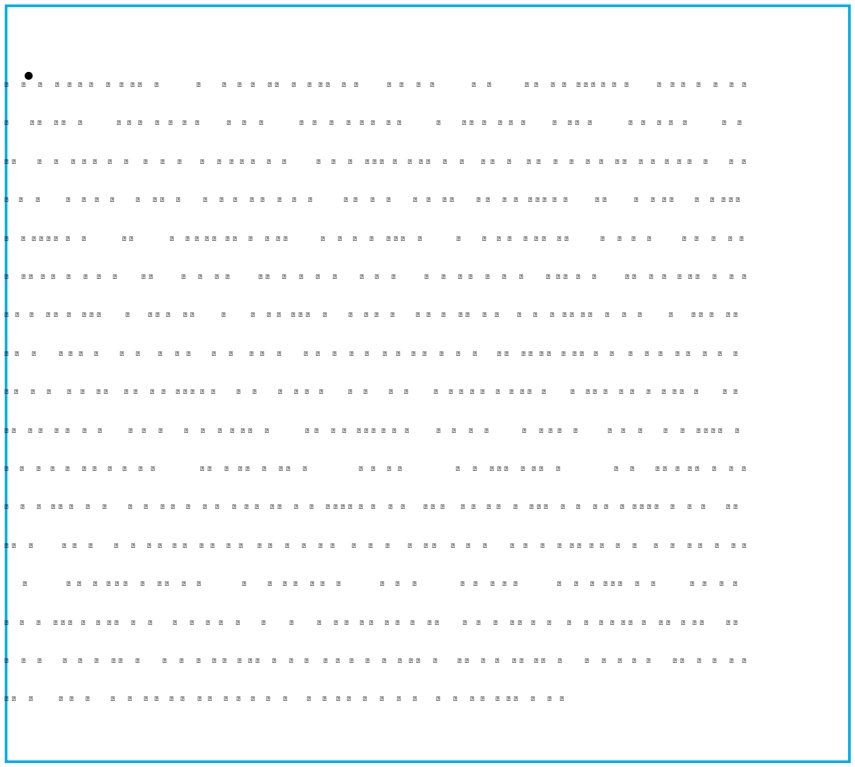

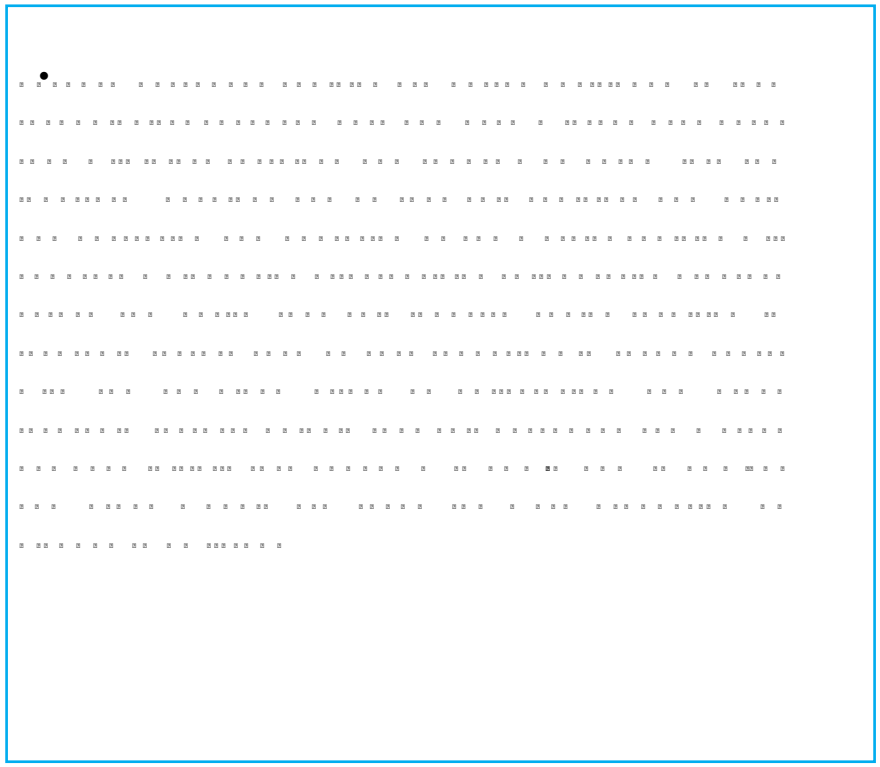

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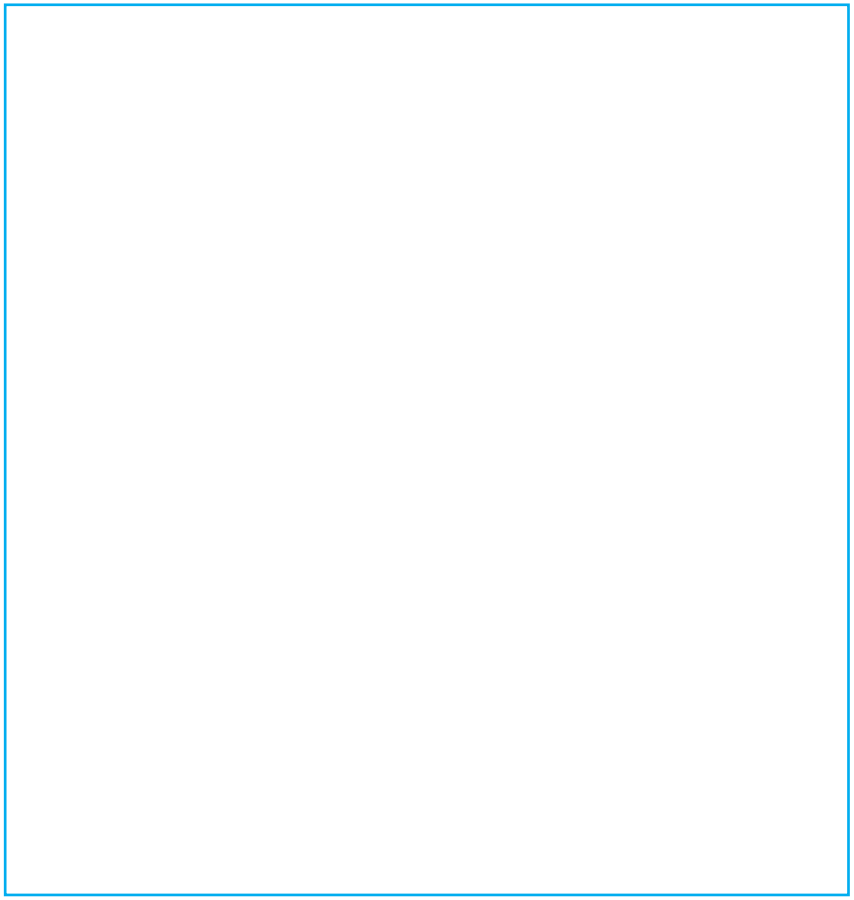

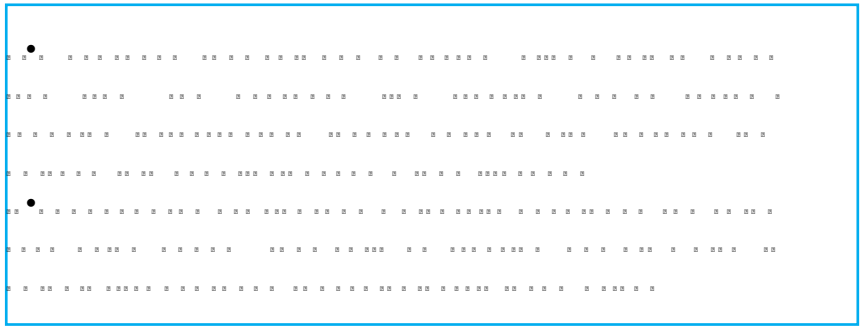

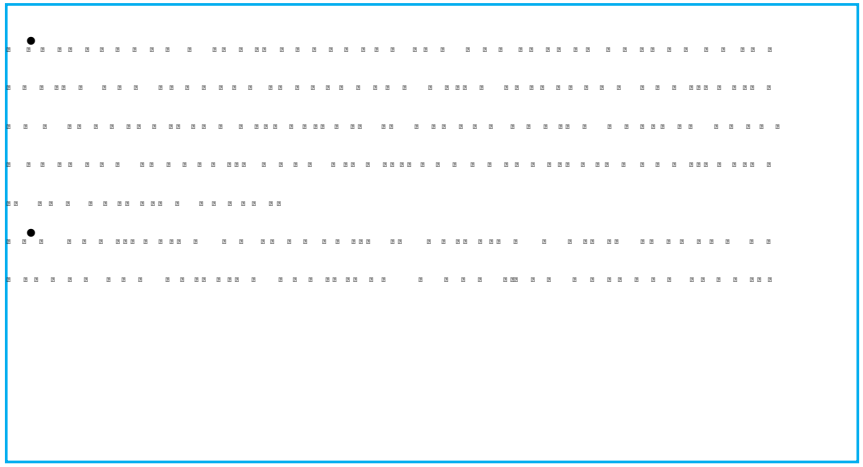

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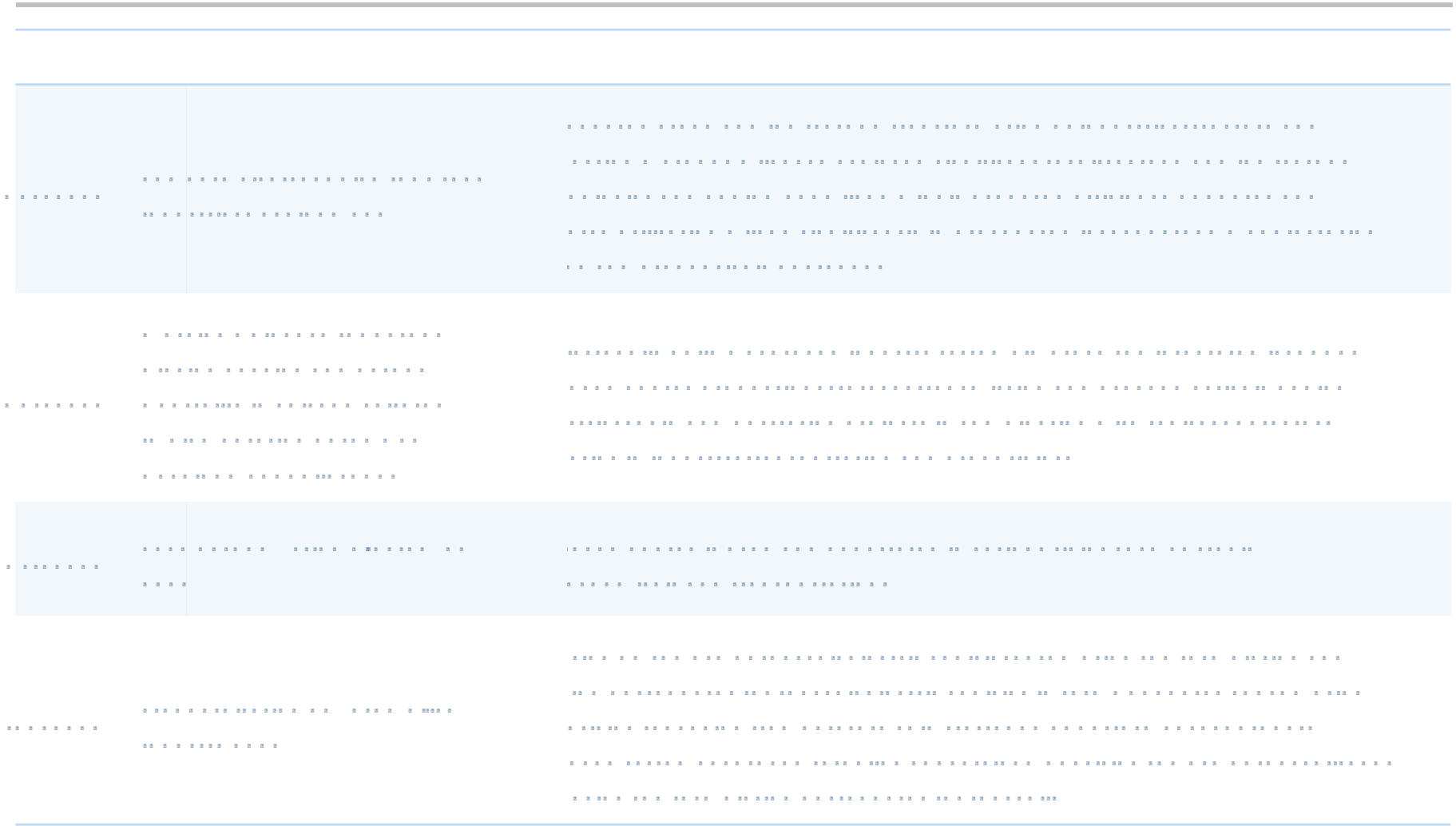

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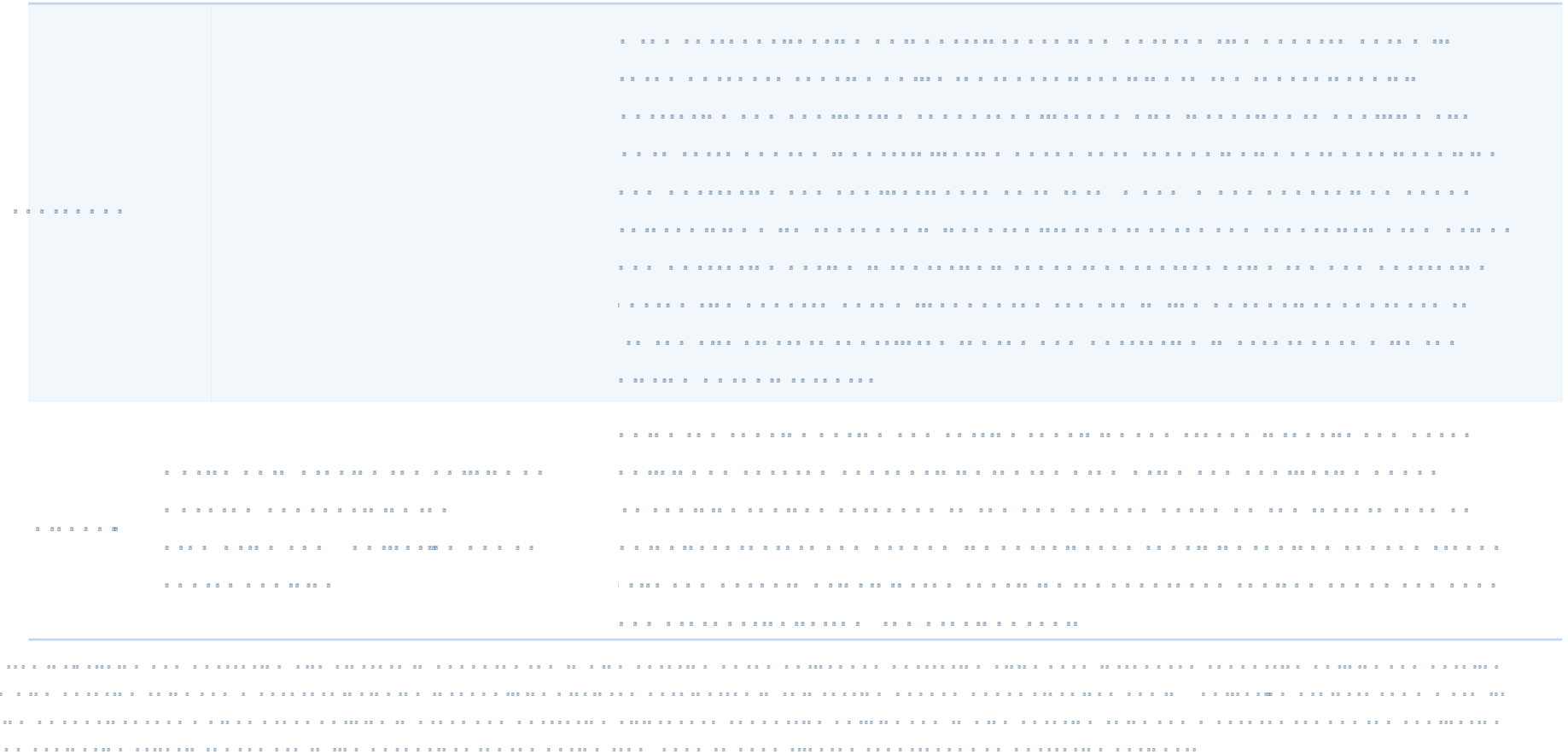

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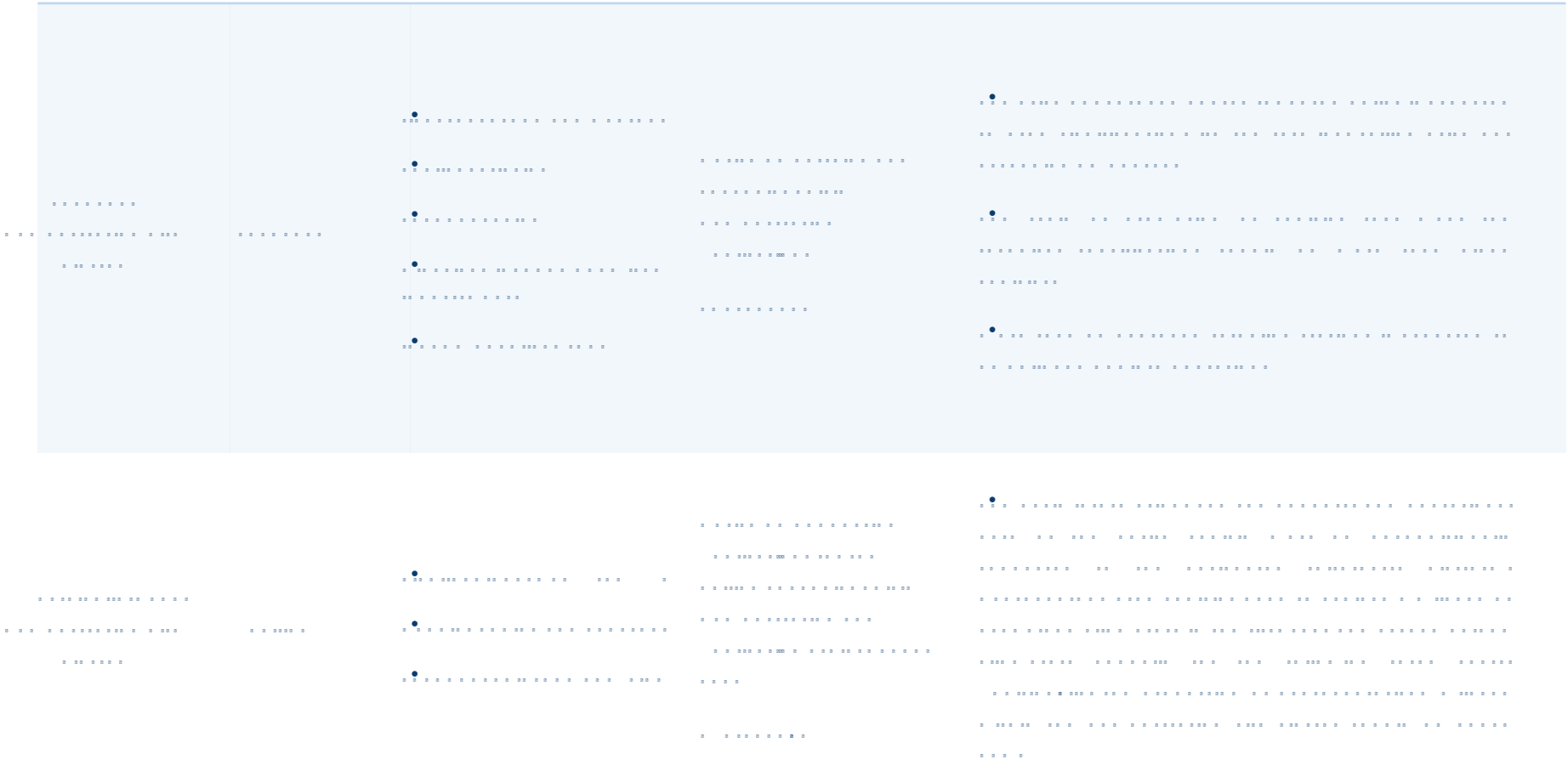

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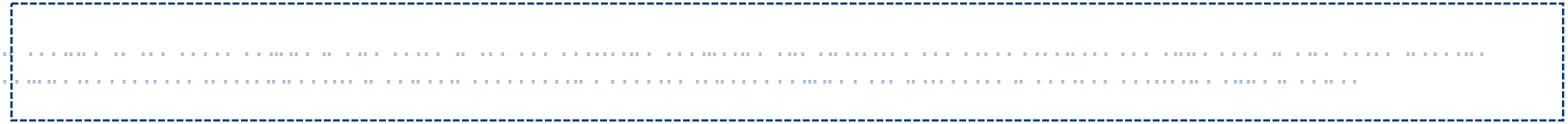

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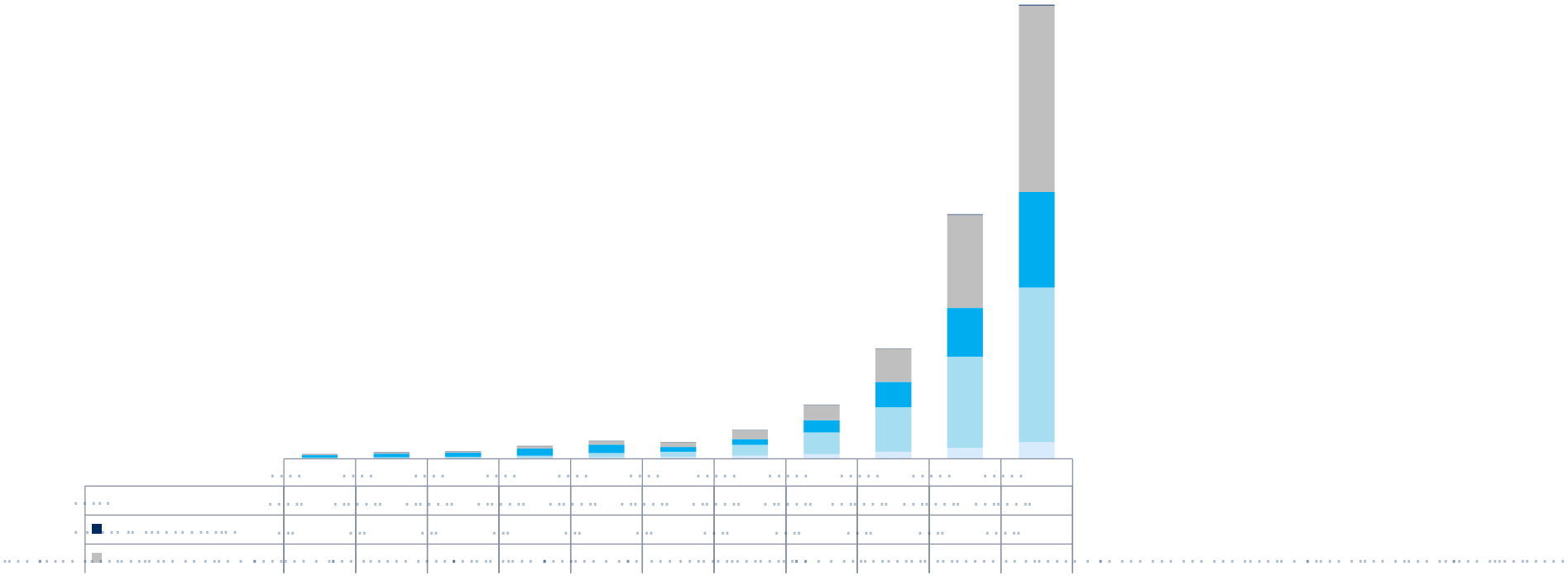
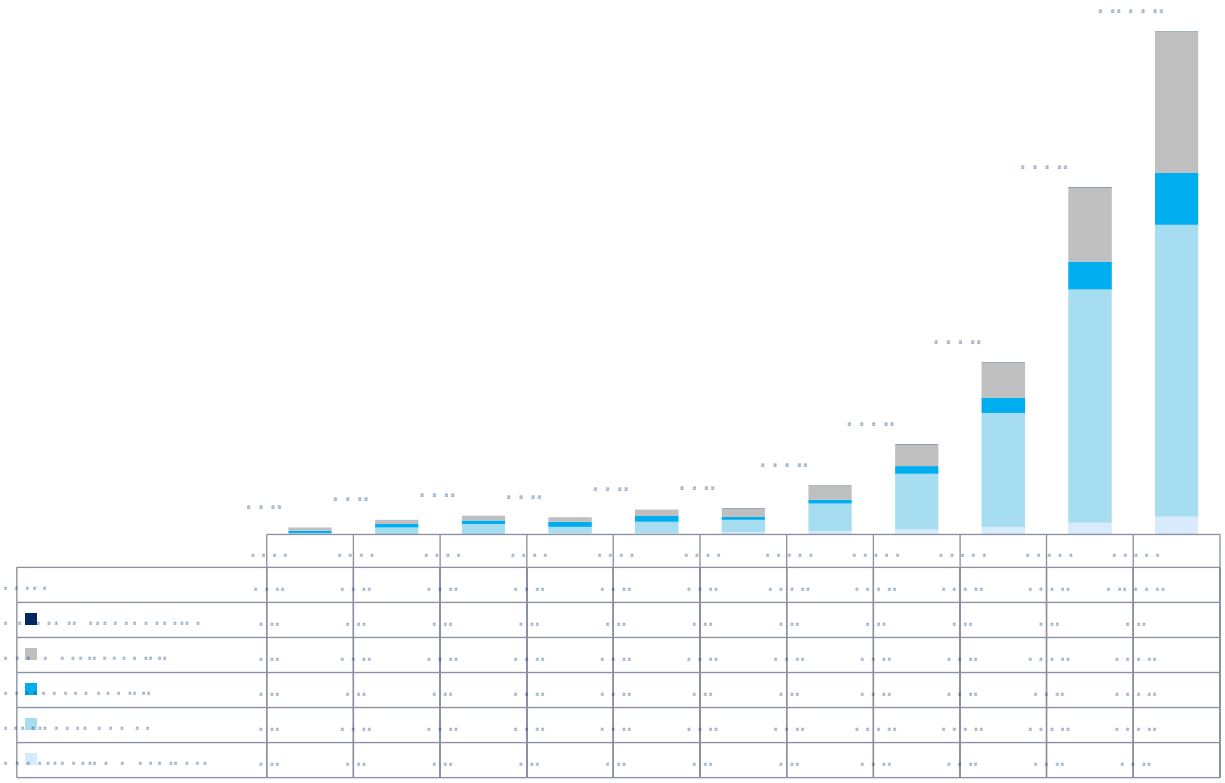
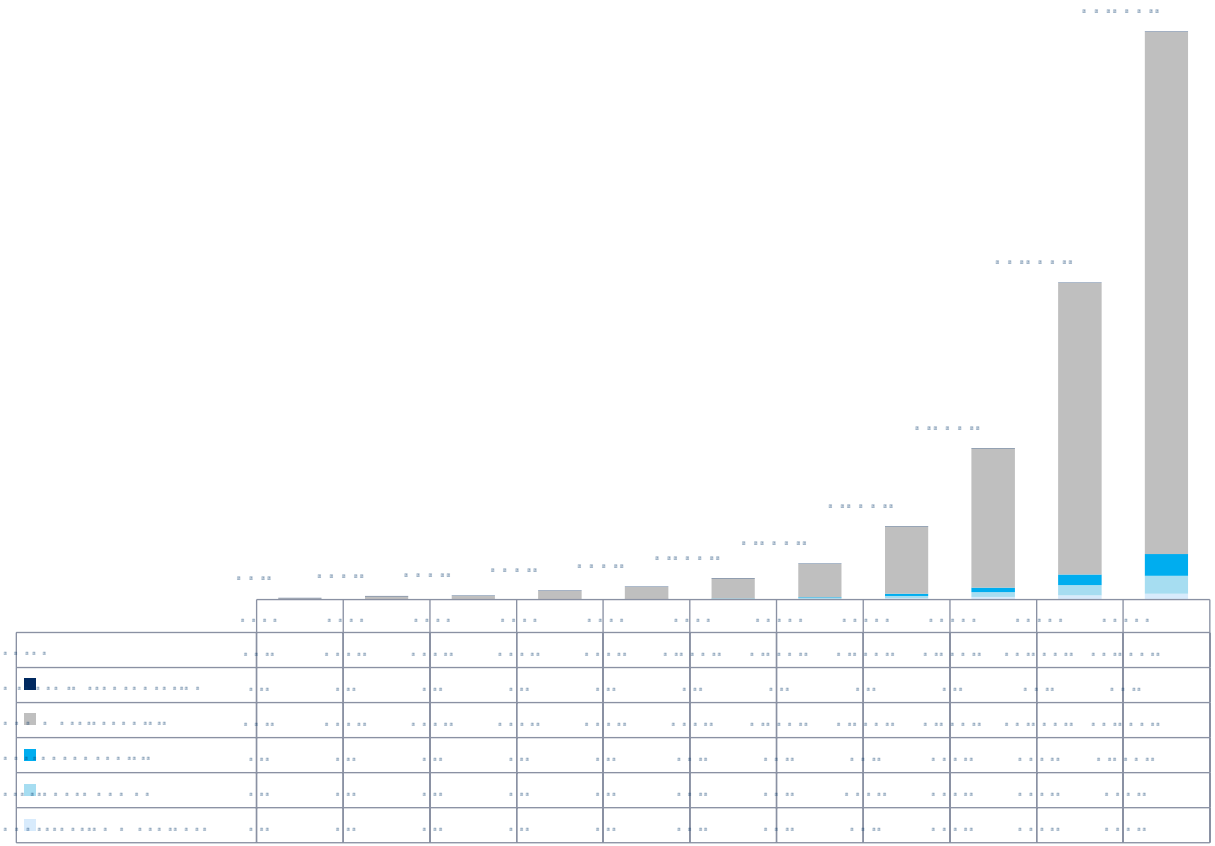




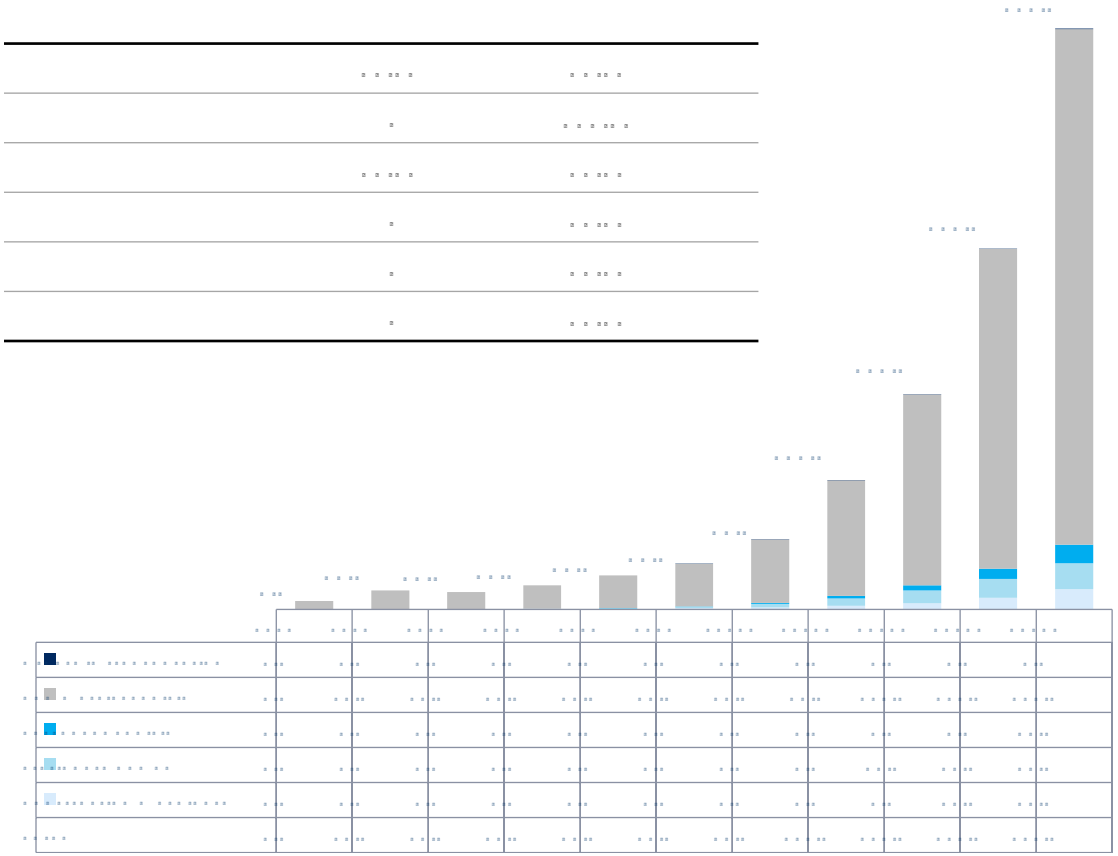
Source: E4tech, Frost & Sullivan

Source: Frost & Sullivan

Source: Frost & Sullivan

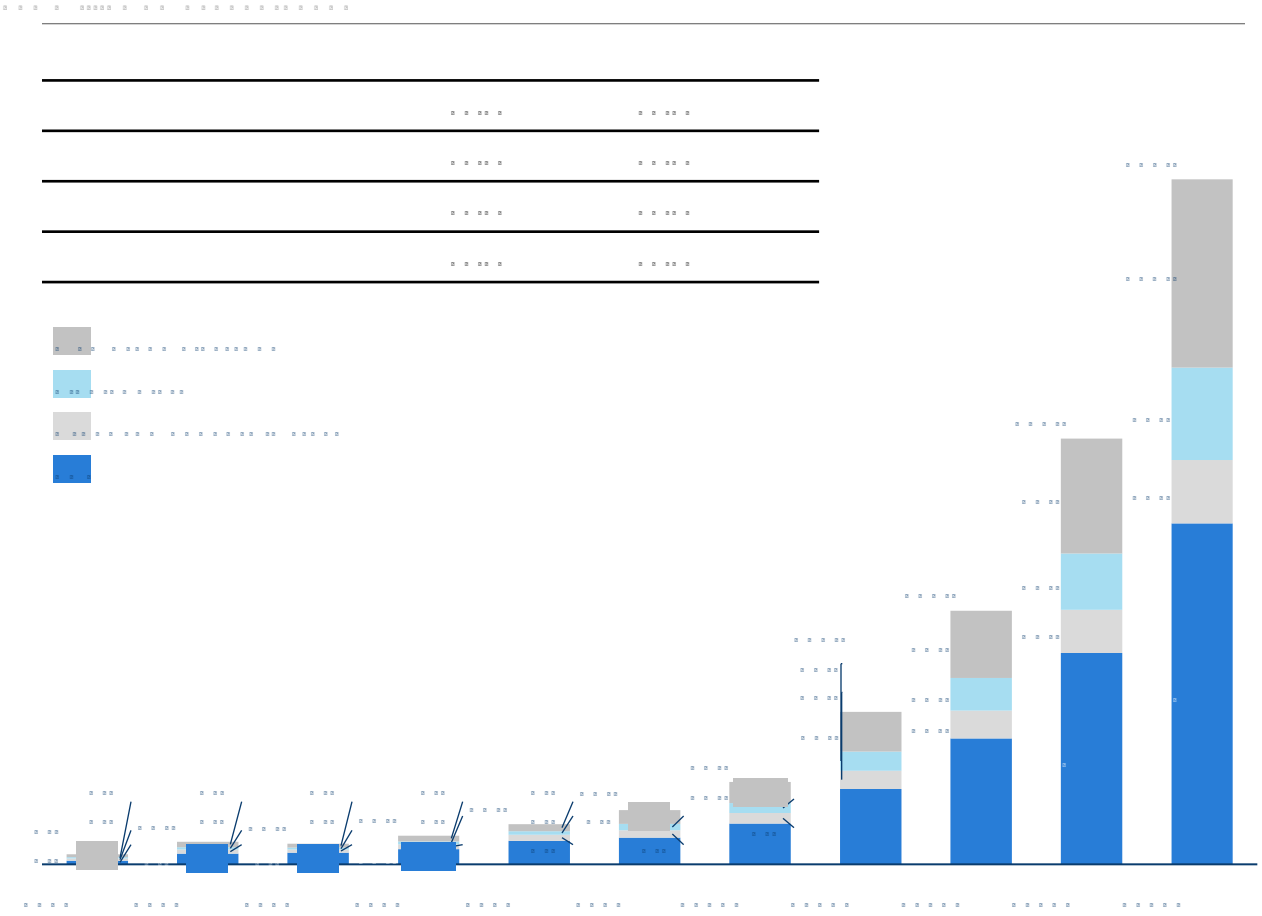


Source: GGII, E4tech, Ministry of Industry and Information Technology of the People's Republic of China (MIIT), Frost & Sullivan



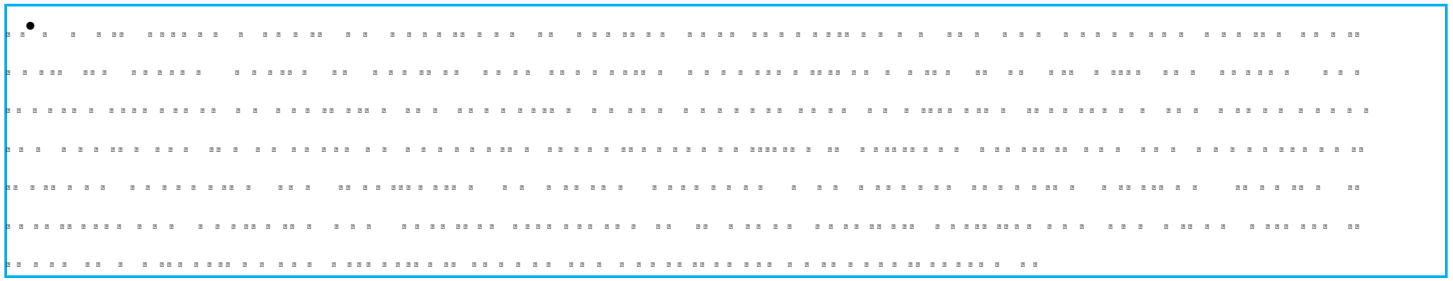
Source: GGII, E4tech, MIIT, Frost & Sullivan

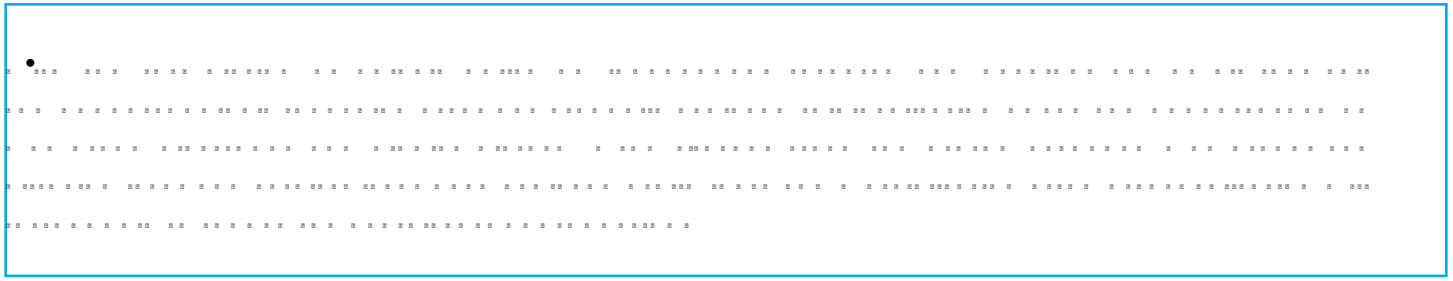
Source: Frost & Sullivan

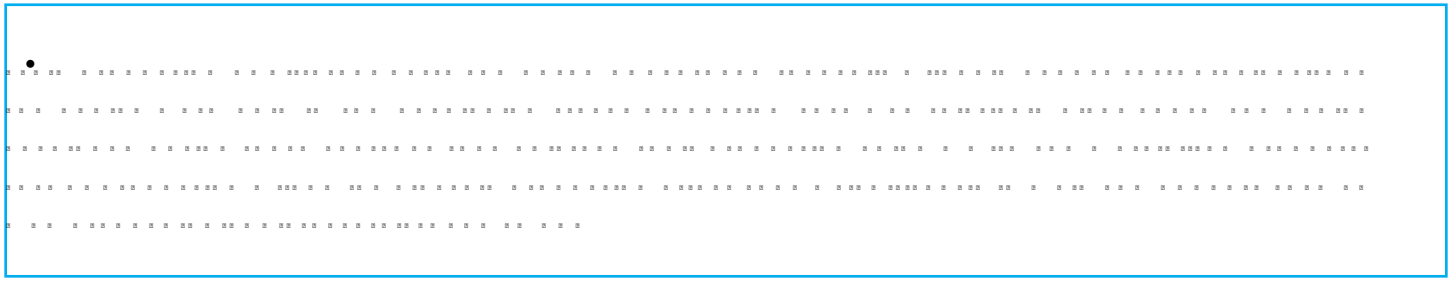


*Note: *The sales value of fuel cell stack comprises the sales value of membrane electrodes, bipolar plates and other components in stacks.*

Source: GGII, E4tech, MIIT, Frost & Sullivan







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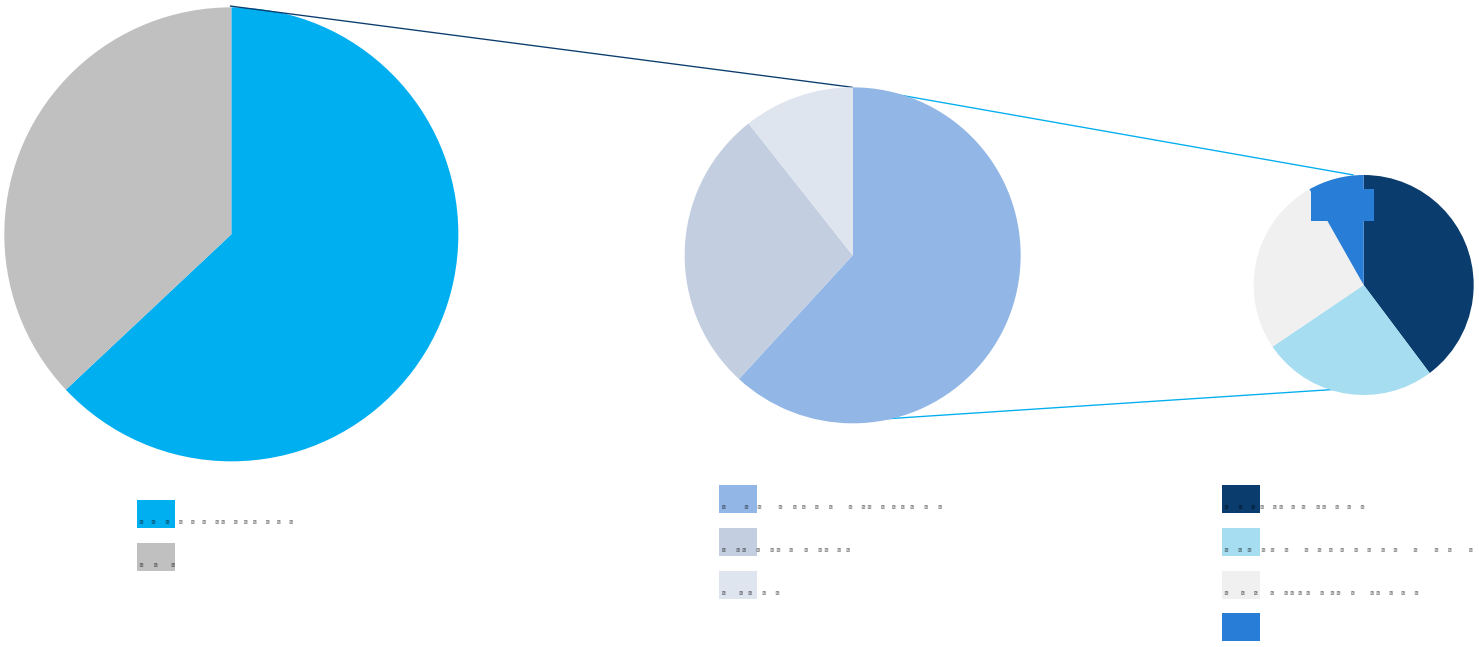

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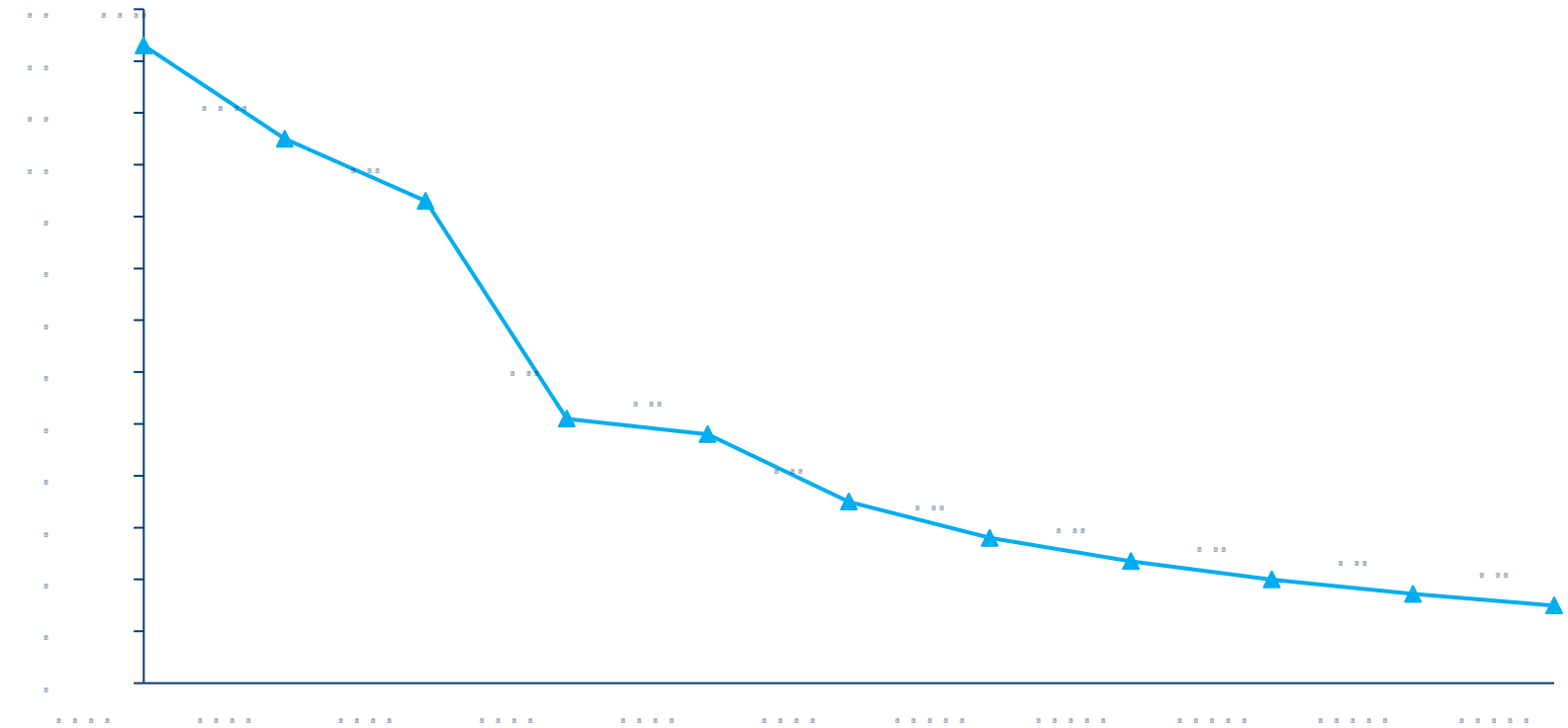
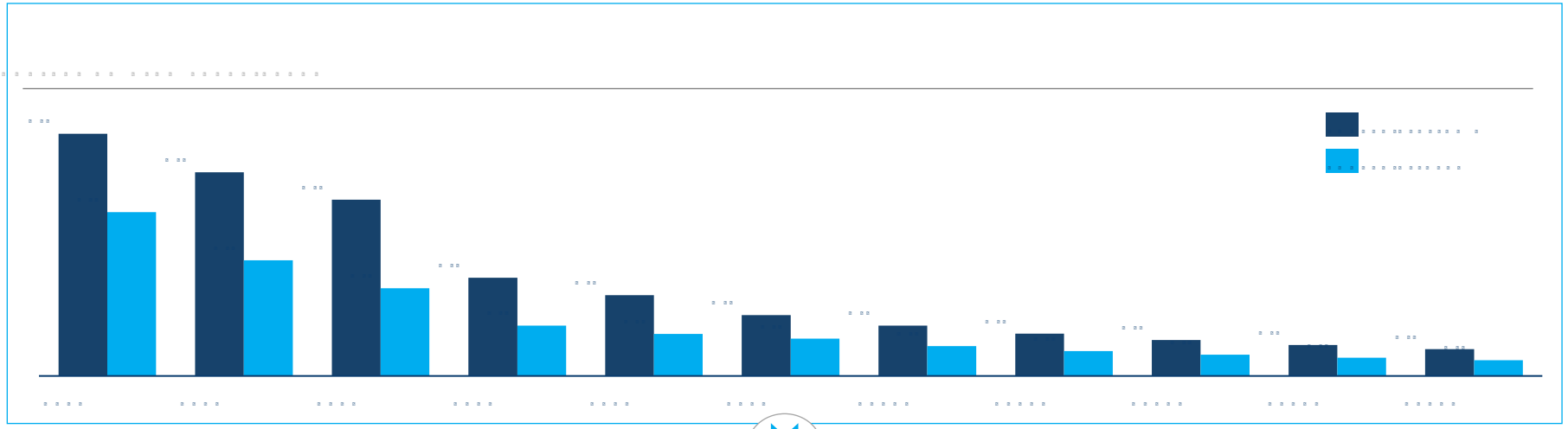
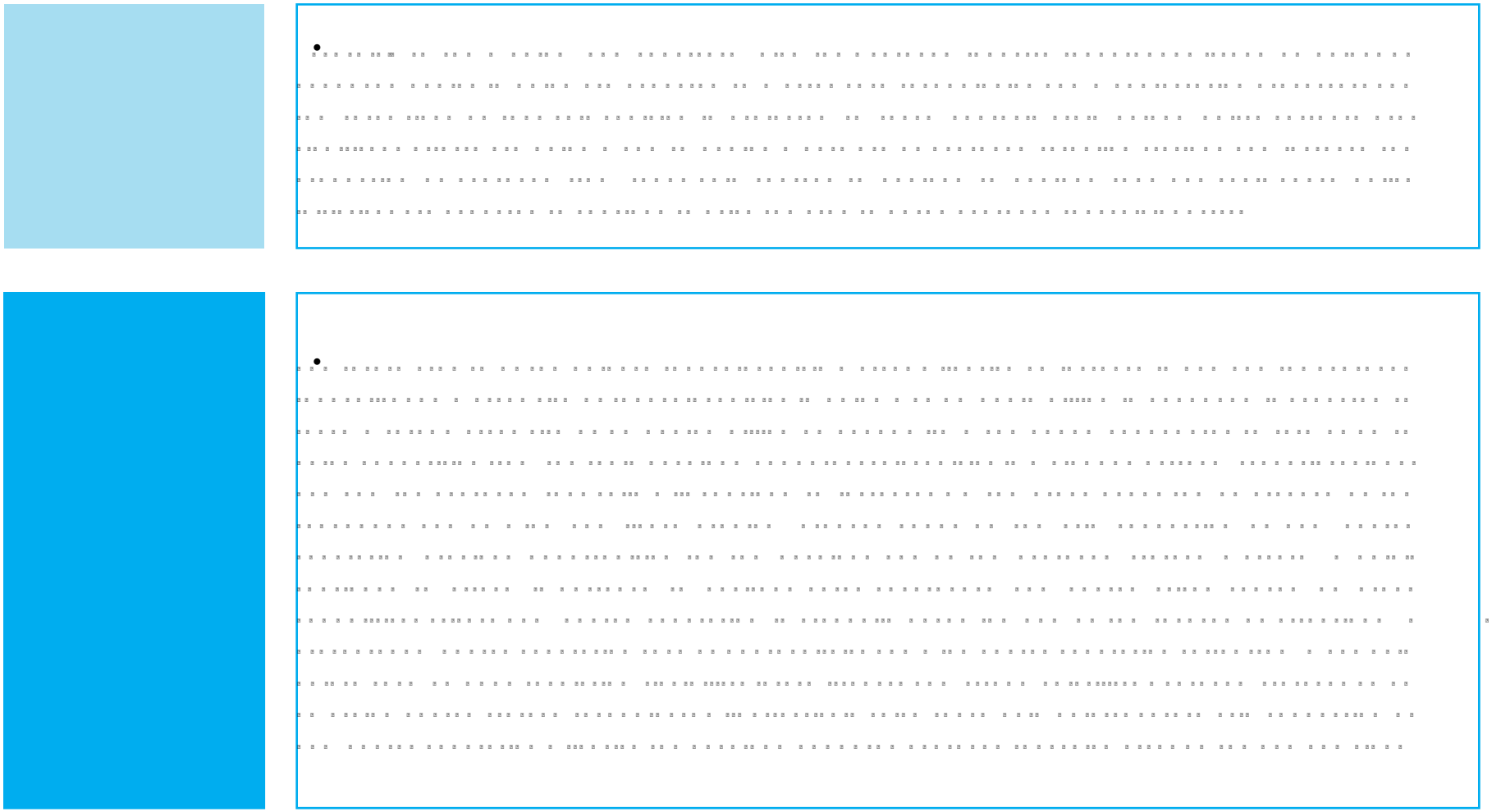


Source: China Society of Automotive Engineers (China-SAE), Frost & Sullivan



Source: China-SAE, Frost & Sullivan



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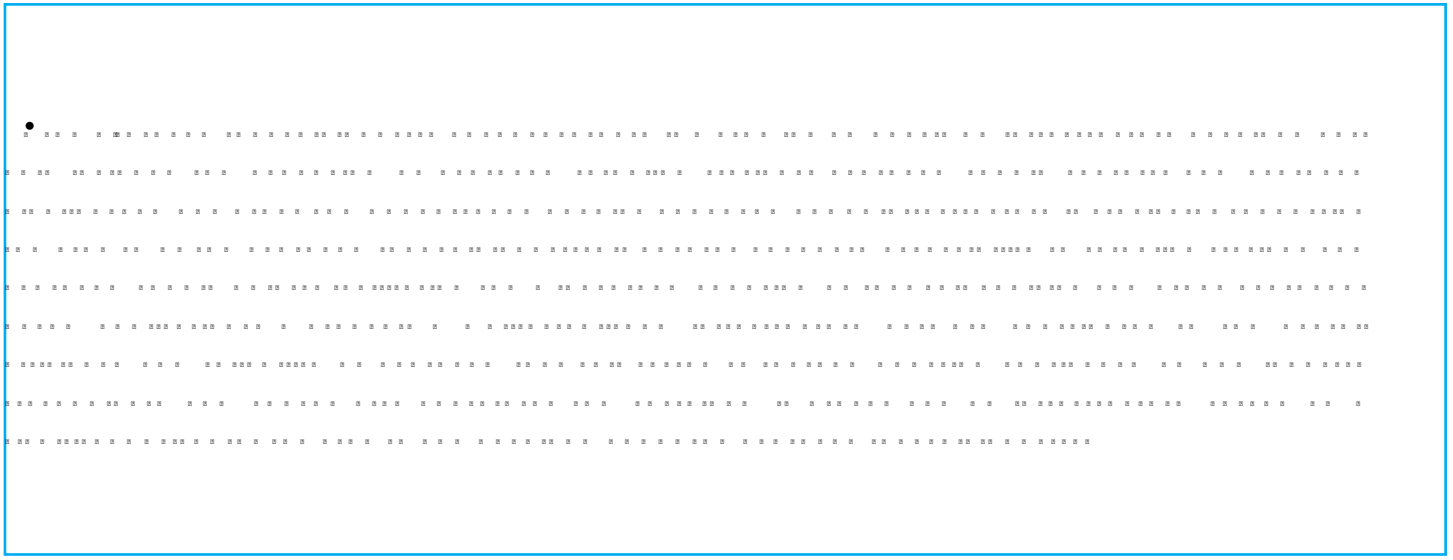

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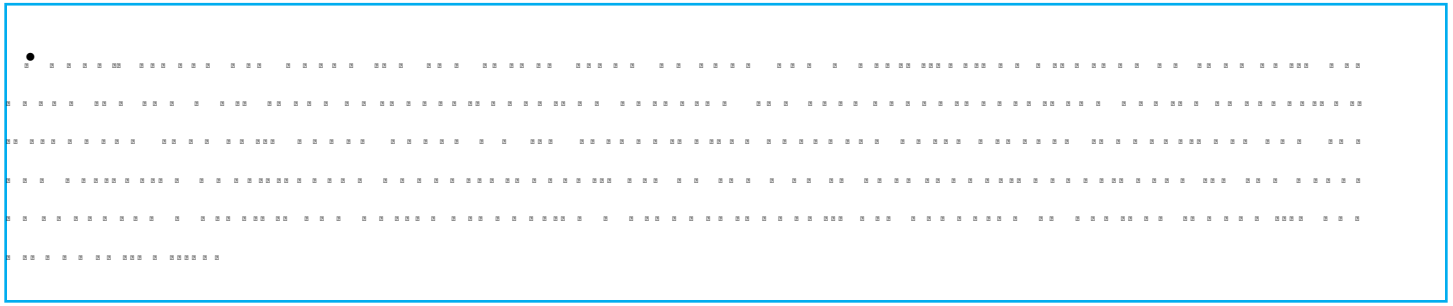

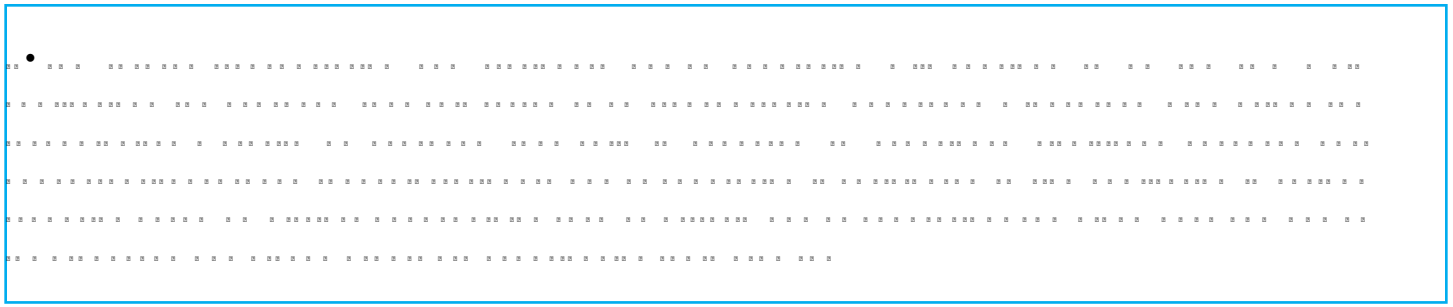

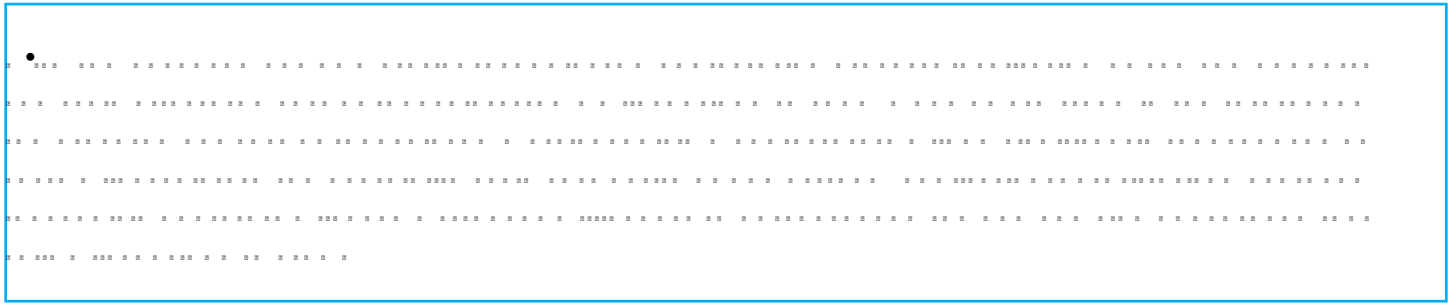

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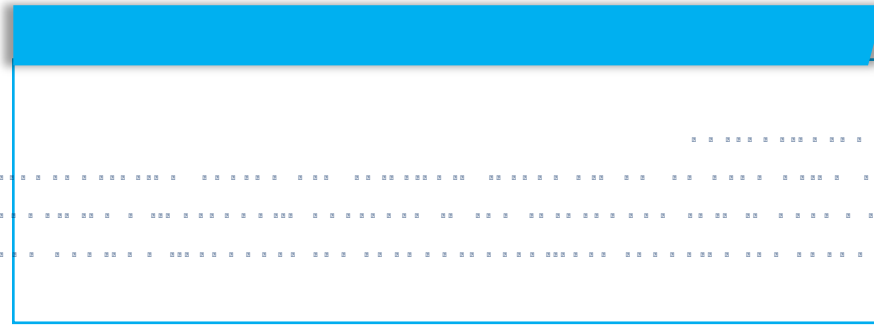

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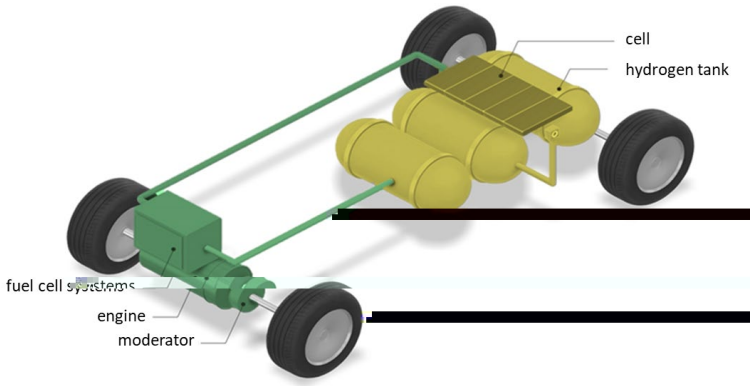

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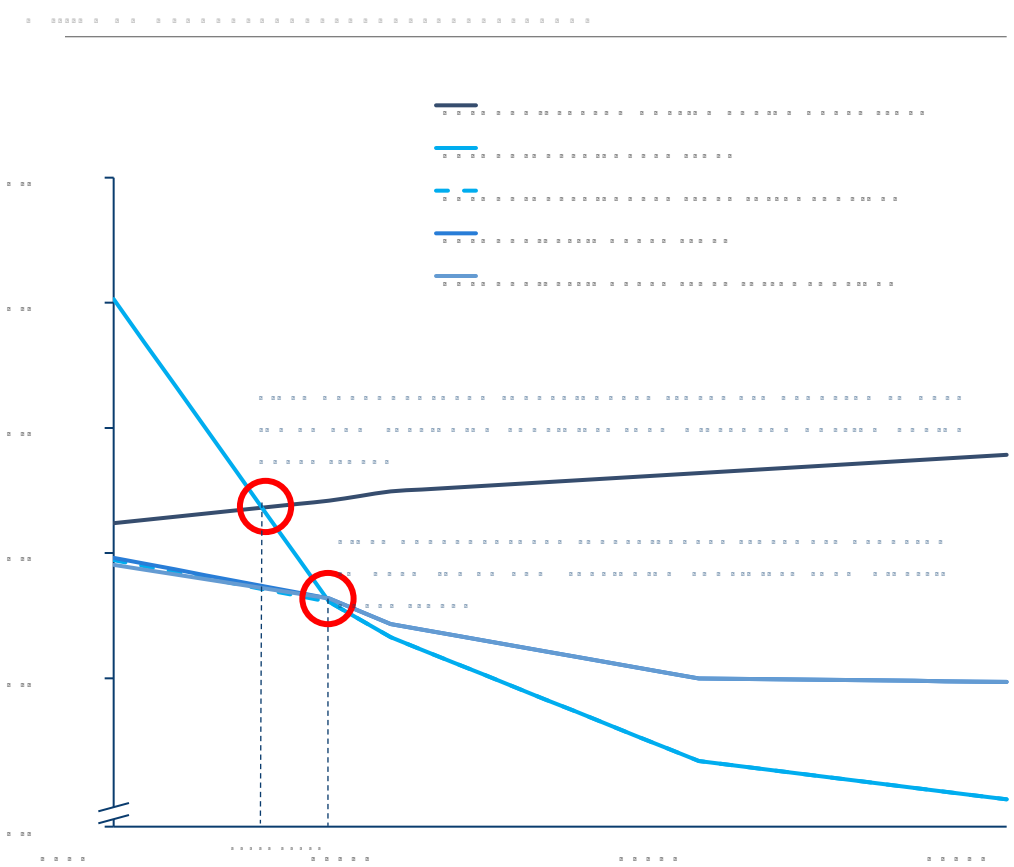

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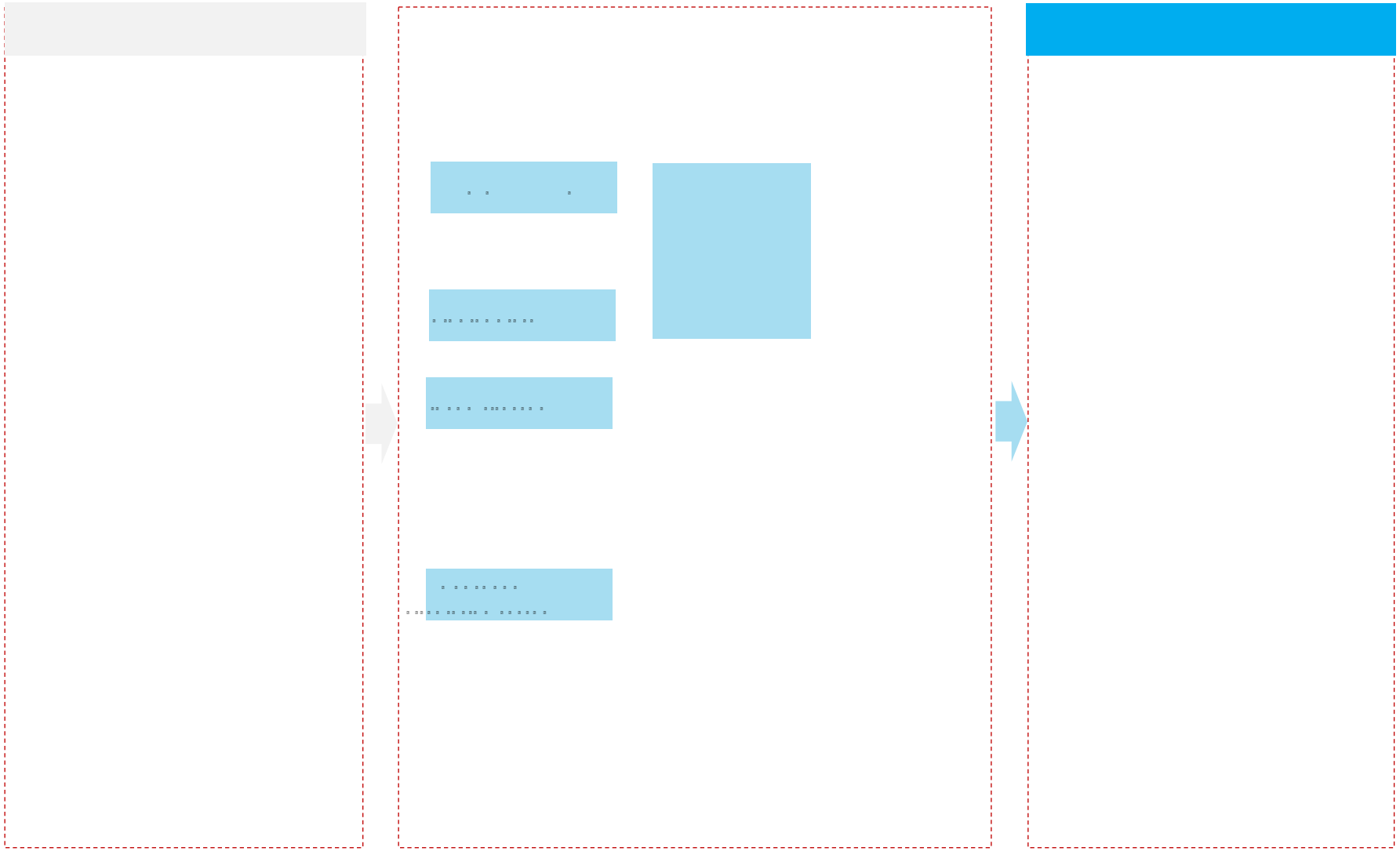

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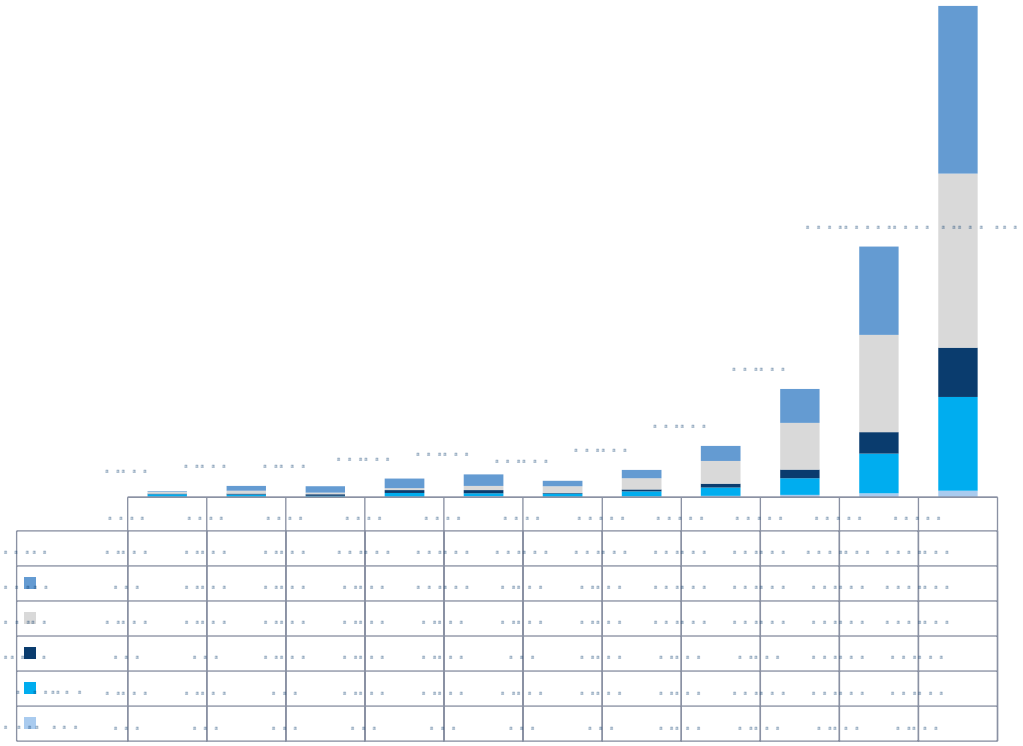
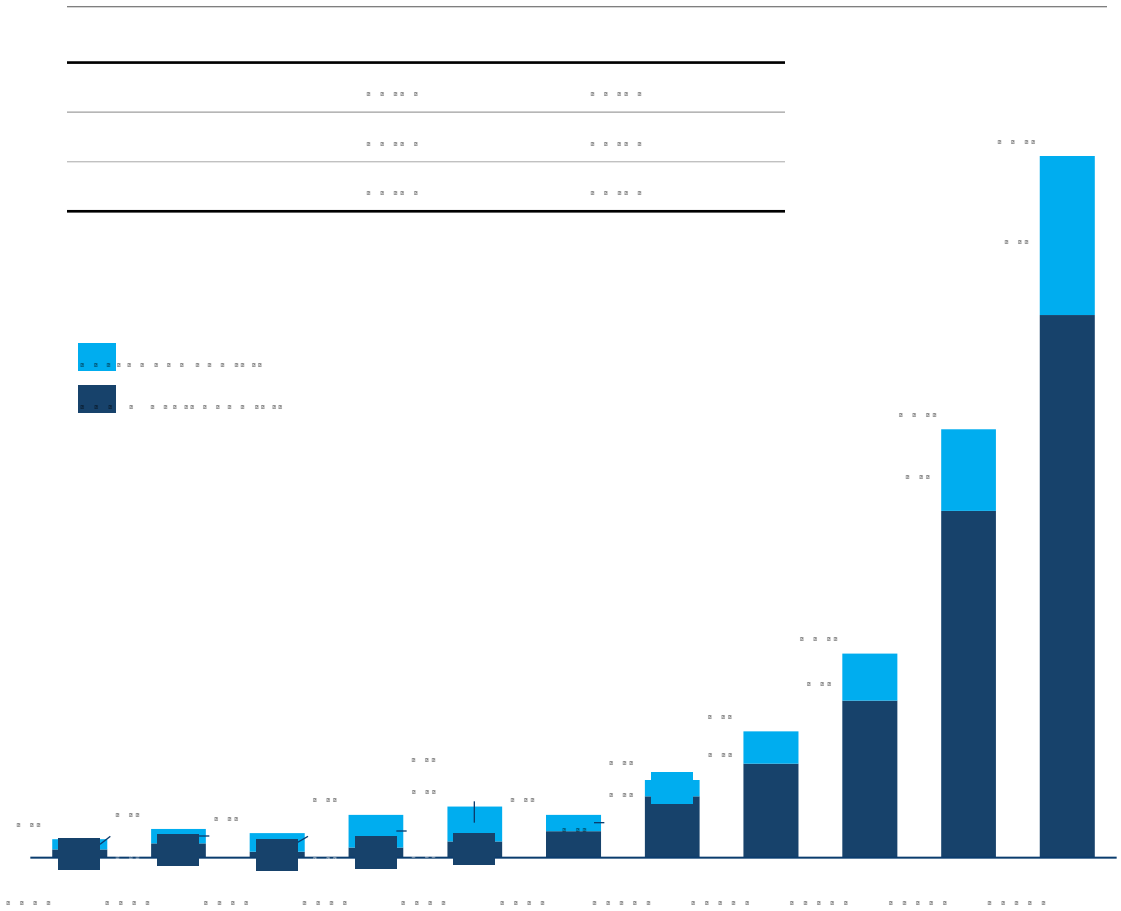




Source: IEA, The Orange Group, Frost & Sullivan

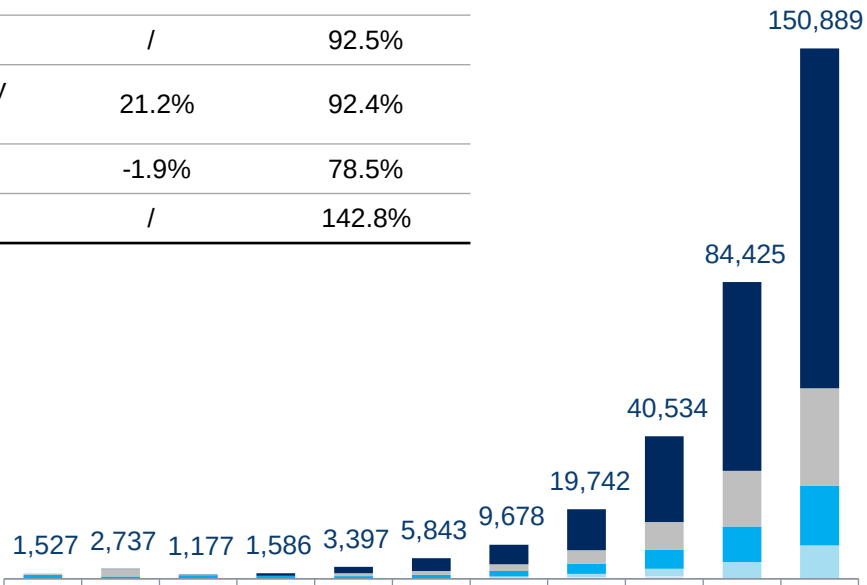
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry, by Sales Volume, by Type

Unit, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	30.8%	91.6%
Heavy trucks	/	92.5%
Medium and Light-duty trucks	21.2%	92.4%
Omnibus	-1.9%	78.5%
Passenger vehicle	/	142.8%



	2018	2019	2020	2021	2022	2023	2024E	2025E	2026E	2027E	2028E
Total	1,527	2,737	1,177	1,586	3,397	5,843	9,678	19,742	40,534	84,425	150,889
Heavy trucks	0	10	20	690	1,829	3,653	5,589	11,625	24,413	53,709	96,676
Medium and Light-duty trucks	402	2,015	128	51	762	1,052	1,914	3,828	7,925	15,849	27,736
Omnibus	1,031	638	947	723	737	935	1,543	2,854	5,365	10,086	16,945
Passenger vehicle	0	0	0	12	29	111	306	941	2,088	4,636	9,365
Others	94	74	82	110	40	92	326	494	743	145	167

Key Findings

- In 2023, China holds approximately a 41.2% share of the global FCEV market in terms of sales volume
- From 2018 to 2023, the overall fuel cell vehicle market in China grew from 1,527 units in 2018 to 5,843 units in 2023, representing a CAGR of 30.8%. The government has vigorously promoted establishing hydrogen energy demonstration zones and cities since 2021. Therefore, driven by strong policy support, continuous breakthroughs in core tech, improved infrastructure, and a further reduction in production costs With further acceleration of market development and the gradual popularization of passenger cars, the production of fuel cell vehicles will gradually form a scale effect. It is expected that China's fuel cell vehicle sales will increase to 150,889 units in 2028.

Source: GGII, China Association of Automobile Manufacturers, CPCA, Frost & Sulliv

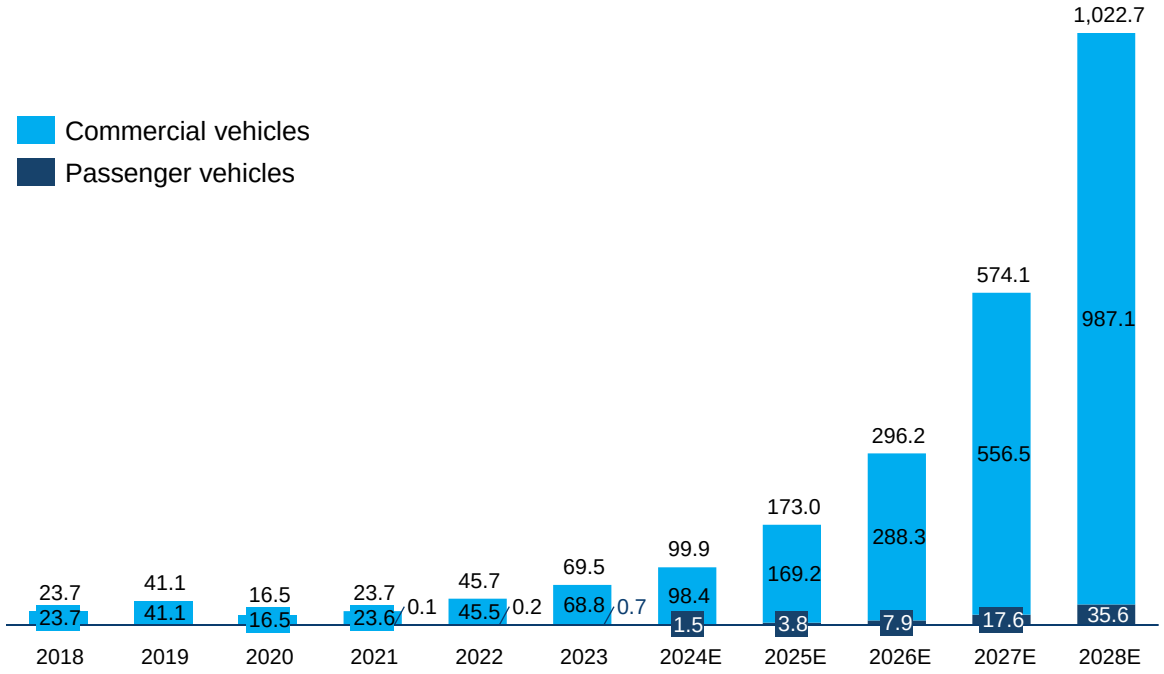
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry, by Sales Value, by Type

100 Million RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	24.0%	71.2%
Commercial vehicle	23.8%	70.4%
Passenger vehicle	/	119.4%



KeyFindings

- In 2023, China holds approximately a 47.3% share of the global FCEV market in terms of sales value
- China's fuel cell vehicle market size grew from RMB2.37 billion in 2018 to RMB6.95 billion in 2023, with a CAGR of 24.0%. Driven by strong policy support, continuous breakthroughs in core technologies, improved infrastructure such as hydrogen refueling stations, and a further reduction in production costs, China's hydrogen fuel cell vehicle sales will usher in a high-speed growth phase similar to that of electric vehicles The fuel cell vehicle market is expected to reach a size of RMB102.3 billion by 2028, with a CAGR of 71.2%.

Source: GGII, China Association of Automobile Manufacturers, CPCA, Frost & Sulliv

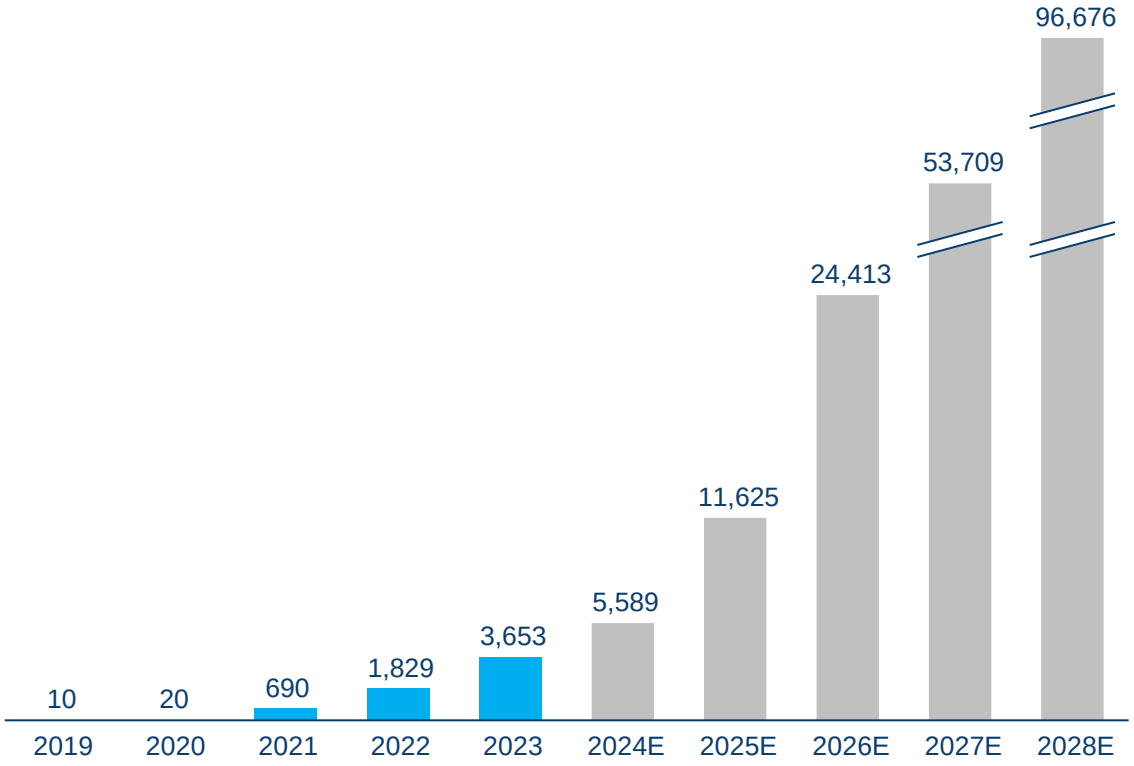
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Heavy Truck Industry

Market Size of China Fuel Cell Heavy Truck Industry, by Sales Volume

Unit, 2019-2028E

CAGR	2019-2023	2023-2028E
Heavy truck	337.2%	92.5%



KeyFindings

- China's fuel cell heavy truck sales volume is 3,653 units in 2023 and is expected to be 96,676 units in 2028, with a CAGR as high as 92.5%. Combined with its rising penetration rate in the overall domestic automobile market, the fuel cell heavy truck market is growing rapidly, and the development strategy of fuel cells mainly applied to heavy trucks is promising in the future, with good prospects

Source: Frost & Sullivan

Market Analysis of the Fuel Cell Electric Vehicle Industry

Future Trend of China Fuel Cell Electric Vehicle Industry

Future Trend	
Fuel cell heavy trucks will become an important commercialized application area	• Firstly, under the "dual-carbon" target, carbon reduction requirements for both the supply side and demand side of the heavy truck industry were put forward, which will accelerate the substitution of hydrogen-energy heavy trucks for fuel-heavy trucks. • Secondly, compared with heavy trucks using lithium batteries, fuel cell heavy trucks have four major advantages high load efficiency, ease of long-distance transportation, ease of low-temperature start-up, and fast replenishment. • In the future, policy support and cost reduction will further drive the TCO of heavy trucks to decrease. Thus, the commercialization process of heavy trucks will be accelerated which means heavy trucks are heading towards one of the main commercialization areas in the FCEV industry.
Northwest region will be a crucial area for FCEV development	• The price of electricity for large industries in China's Northwest region is generally below the national average, which is more favorable for the development of hydrogen production from water electrolysers to save energy consumption. With the lower cost of using hydrogen, the Northwest region in China will be a crucial area for FCEV development
Fields of application will continue to diversify	• After commercialization application in omnibuses and logistics, future application of FCEV is expected to expand to more fields. Along with the technological development and cost reduction of hydrogen energy and fuel cell systems, it will expand towards rail transportation and passenger vehicles on specific routes, intercity logistics, intercity passenger transportation, and other fields. Considering the differences in the energy structure of different regions, FCEV and electric vehicles will enter a long-term coexistence and complement each other's market applications

Source: Frost & Sullivan

Market Analysis of the Fuel Cell Electric Vehicle Industry

Future Trend of China Fuel Cell Electric Vehicle Industry

Future Trend	
The Promotion of Fuel Cell Electric Vehicle is Transitioning from Policy-driven to Market-driven	• In the short term, incentive policies play a crucial role in propelling the development of the fuel cell electric vehicle industry. However, in the medium to long term, the widespread adoption of fuel cell electric vehicles will gradually shift away from dependence on policy subsidies and expand from demonstration city clusters to non-demonstration cities. The extensive adoption of fuel cell electric vehicles depends largely on the Total Cost of Ownership (TCO). When the TCO of fuel cell electric vehicles becomes lower than that of traditional fuel vehicles, they become a viable alternative • The TCO of fuel cell electric vehicles is primarily composed of purchase costs and energy usage costs. Advancements in fuel cell technology are continuously reducing the purchase price of fuel cell electric vehicles. In addition, progress in upstream production, storage, transportation, and technology is lowering the terminal price of hydrogen, consequently reducing the energy usage costs of these vehicles. Given these cost reduction factors, the current industry trend is to promote fuel cell electric vehicles in regions abundant in low-price hydrogen resources, with a primary focus on areas with rich industrial by-product hydrogen resources. Taking into account the current status of technological development, industrial by-product hydrogen represents a low-cost method of hydrogen production. Promoting fuel cell electric vehicles in these regions translates to lower energy consumption costs and a reduced TCO, making them more economically competitive compared to traditional fuel vehicles. For instance, in Shanxi province, where chemical enterprises such as coke plants, steel mills, and chlor-alkali plants are concentrated, there exists a robust industrial foundation for industrial by-product hydrogen. From the supply side, fuel cell electric vehicles in these regions provide businesses with lower transportation costs, and from the demand side, industries in low-price hydrogen regions, particularly chemical enterprises, exhibit a demand for long-distance transportation precisely the downstream application area where fuel cell electric vehicles targeted to. In China, as of 2022, there are over one million heavy trucks utilized in bulk cargo transportation scenarios. Consequently, the future market for fuel cell electric vehicles will gradually expand into regions with low-price hydrogen, eventually replacing traditional fuel vehicles. Even in scenarios where future policy subsidies diminish, fuel cell electric vehicles continue to possess extensive application scenarios and can maintain a high growth rate.

Source: Frost & Sullivan

Agenda

1. Overview of Hydrogen Industry

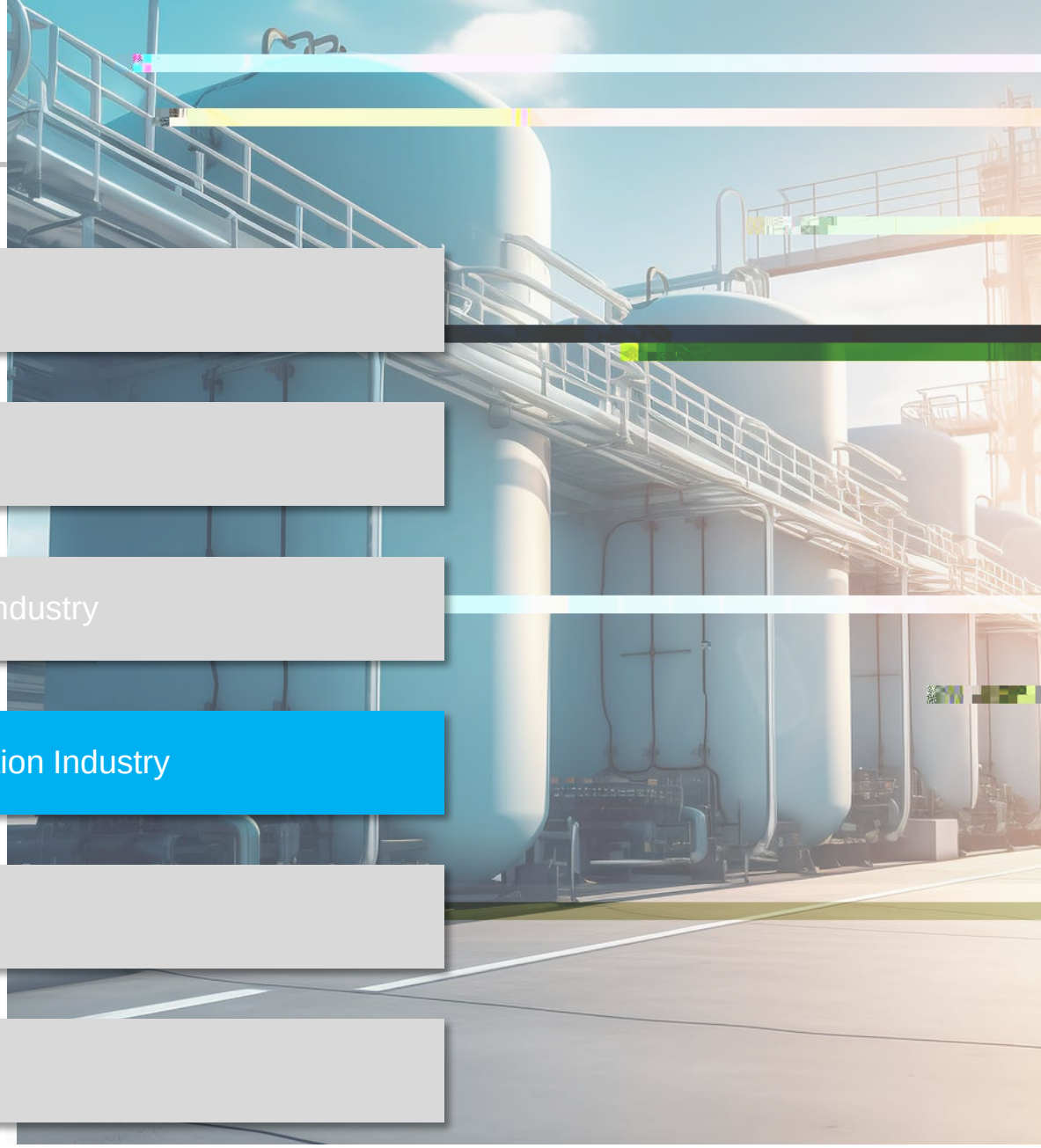
2. Overview of the Fuel Cell Industry

3. Overview of the Fuel Cell Vehicle Industry

4. Overview of the Hydrogen Production Industry

5. Competitive Landscape

6. Appendix



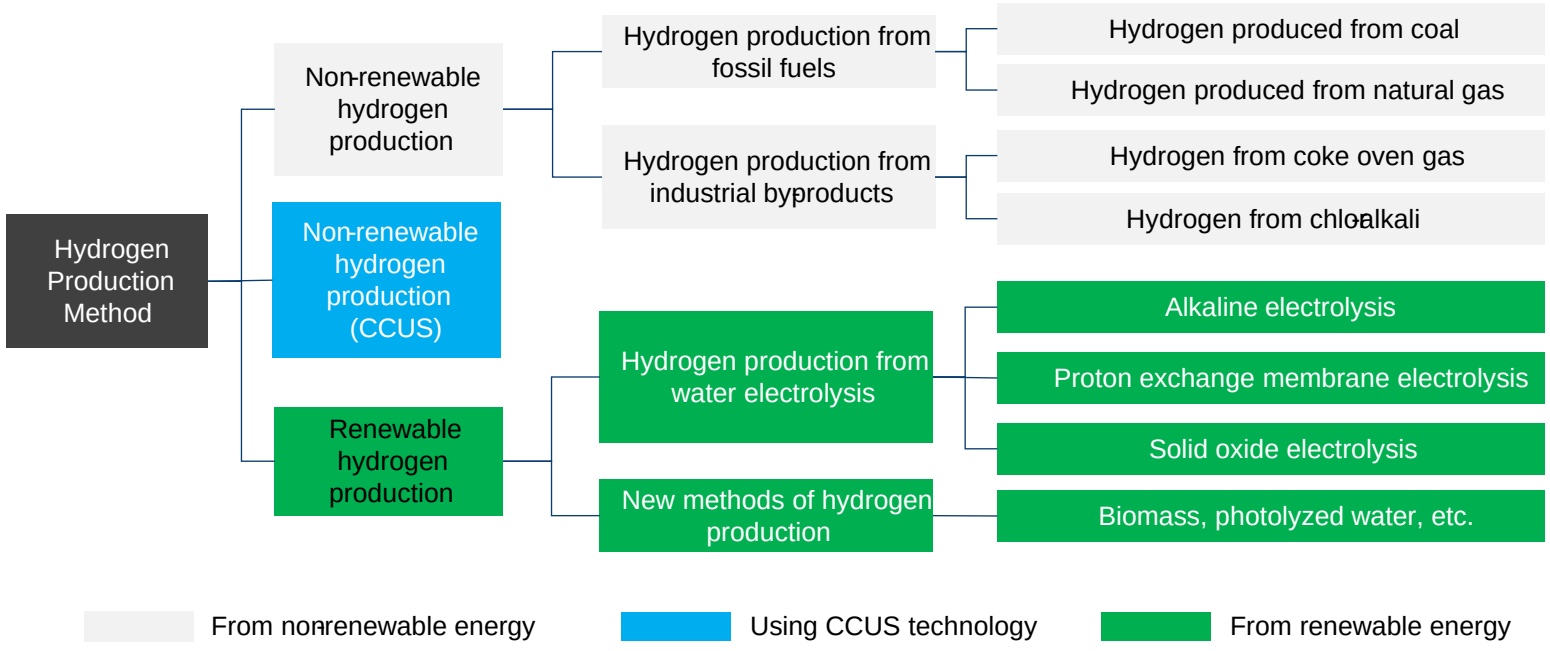
Overview of the Hydrogen Production Industry

Definition and Methods of Hydrogen Production

Definition

- Hydrogen differs from most traditional fossil energy sources as it is produced through man-made chemical processes. Different raw materials can be used to prepare hydrogen. Hydrogen production methods can be divided into two categories: non-renewable hydrogen production and renewable hydrogen production.
- Based on preparation methods, hydrogen can be categorized as: (i) hydrogen produced from traditional sources (such as natural gas or coal), (ii) hydrogen produced by combining traditional sources with CCUS (Carbon Capture, Utilization, and Storage) technology, and (iii) hydrogen produced from renewable energy sources, such as wind power, solar power, photovoltaic, etc.

Methods of Hydrogen Production



Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Comparison of Different Hydrogen Production Technologies

Hydrogen production process		Principles of reaction	Advantages	Disadvantages
Hydrogen production from fossil fuel	Coal	Coal coking and coal gasification	China has rich coal reserves, abundant production, lower costs and mature technology	Greenhouse gas emission
	Natural gas	Steam reforming mainly, some oxidation and catalytic cracking	Lower cost and abundant production	Greenhouse gas emission
Hydrogen production from industry by-products	Coke oven gas	Direct separation and purification of hydrogen by pressure change adsorption	Industrial byproducts, low cost	Air pollution, construction sites limited by raw material supply
	Chlor-alkali	• Sodium chlorate tail gas: deoxygenation and dichlorination, PSA separation and purification • PVC tail gas: pressure change adsorption purification, pressure change adsorption PSA hydrogen extraction	High product purity and abundant raw materials	Construction sites are limited by the availability of raw materials
Hydrogen production from water electrolysis	Alkaline electrolysis (ALK)	Direct current decomposition of water	More mature technology, lower cost	Gas production requires dealkalineand stable power supply
	Proton exchange membrane electrolysis (PEM)		Flexible operation, small equipment size, high output pressure, volatility for renewable power generation	Requires the use of rare metals such as platinum, and iridium, which have high cost and limited supply chain

Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

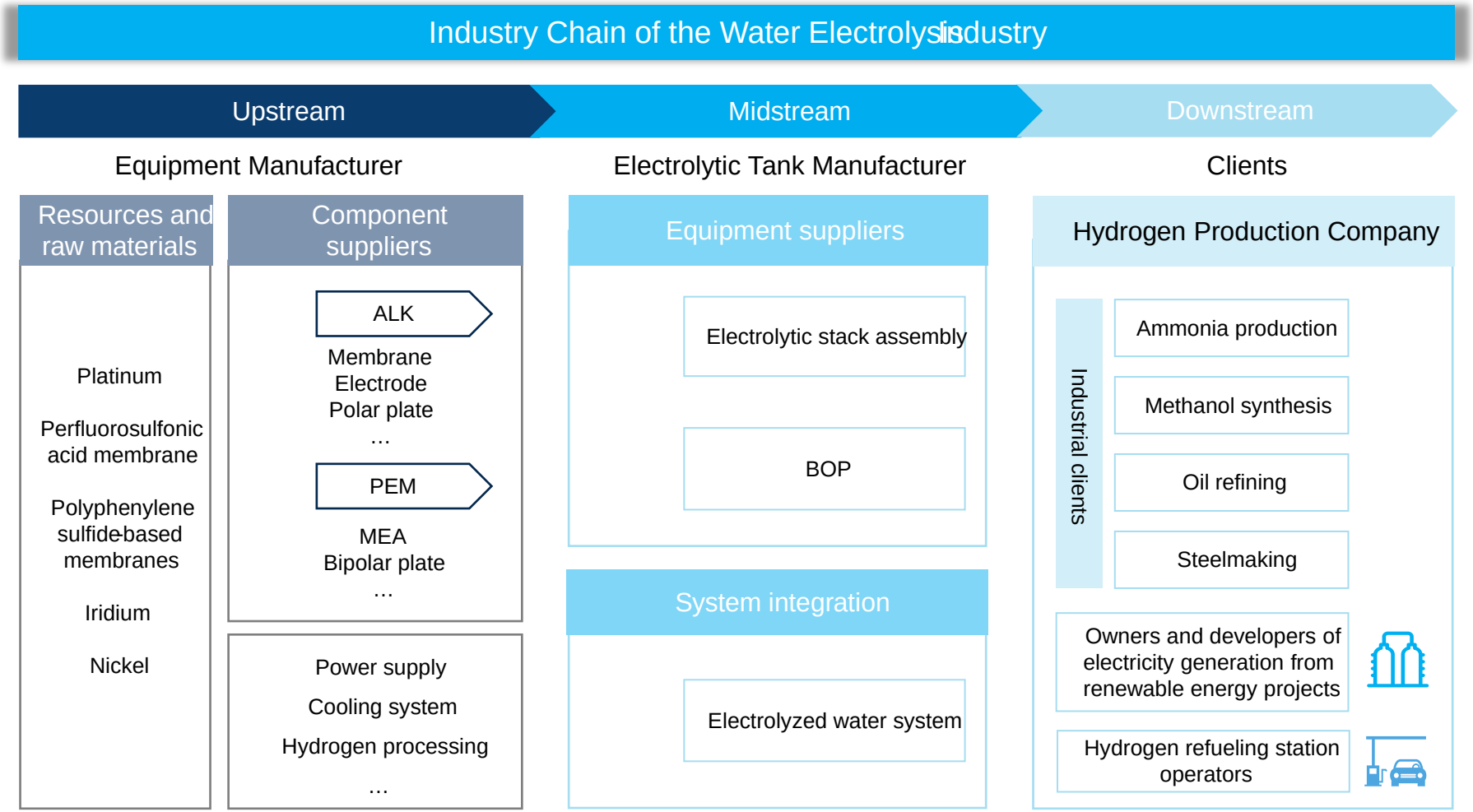
Comparison of Different Hydrogen Production Technologies

	ALK	PEM	SOEC
Electrolytes	20-30% KOH	PEM (Nafion, etc.)	Y_2O_3/ZrO_2
Working temperature	70-90 °C	70-80 °C	700-1,000 °C
Electric density	0.25 A/cm^2	1-3 A/cm^2	1-10 A/cm^2
Energy consumption	4.5-5.5 kWh/Nm^3	3.8-5.0 kWh/Nm^3	3.0-3.6 kWh/Nm^3
Dynamic responsiveness	Faster start/stop	Fast start/stop	Inconvenient start/stop
Electric mass requirements	Relatively strong	Strong	/
System operation and maintenance	Corrosive liquid, complicated operation and maintenance in the later stage, high-cost	No corrosive liquids, simple operation and maintenance, low-	

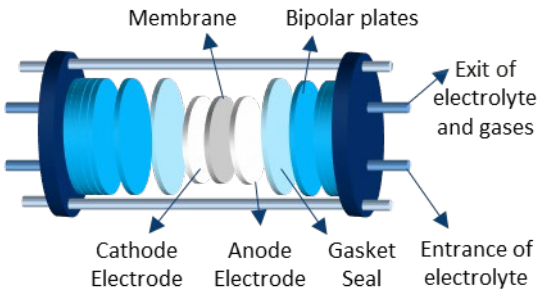
Source: Frost & Sullivan

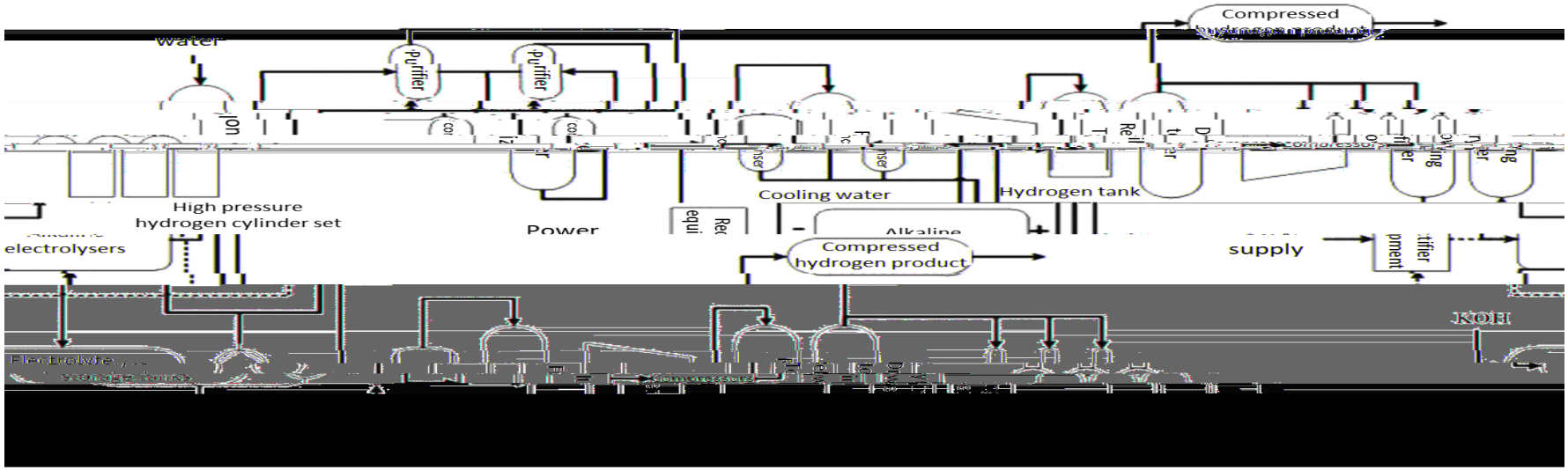
Overview of the Hydrogen Production Industry

Industry Chain of the Hydrogen Production from Water Electrolysis



Source: Frost & Sullivan





Source: Frost & Sullivan

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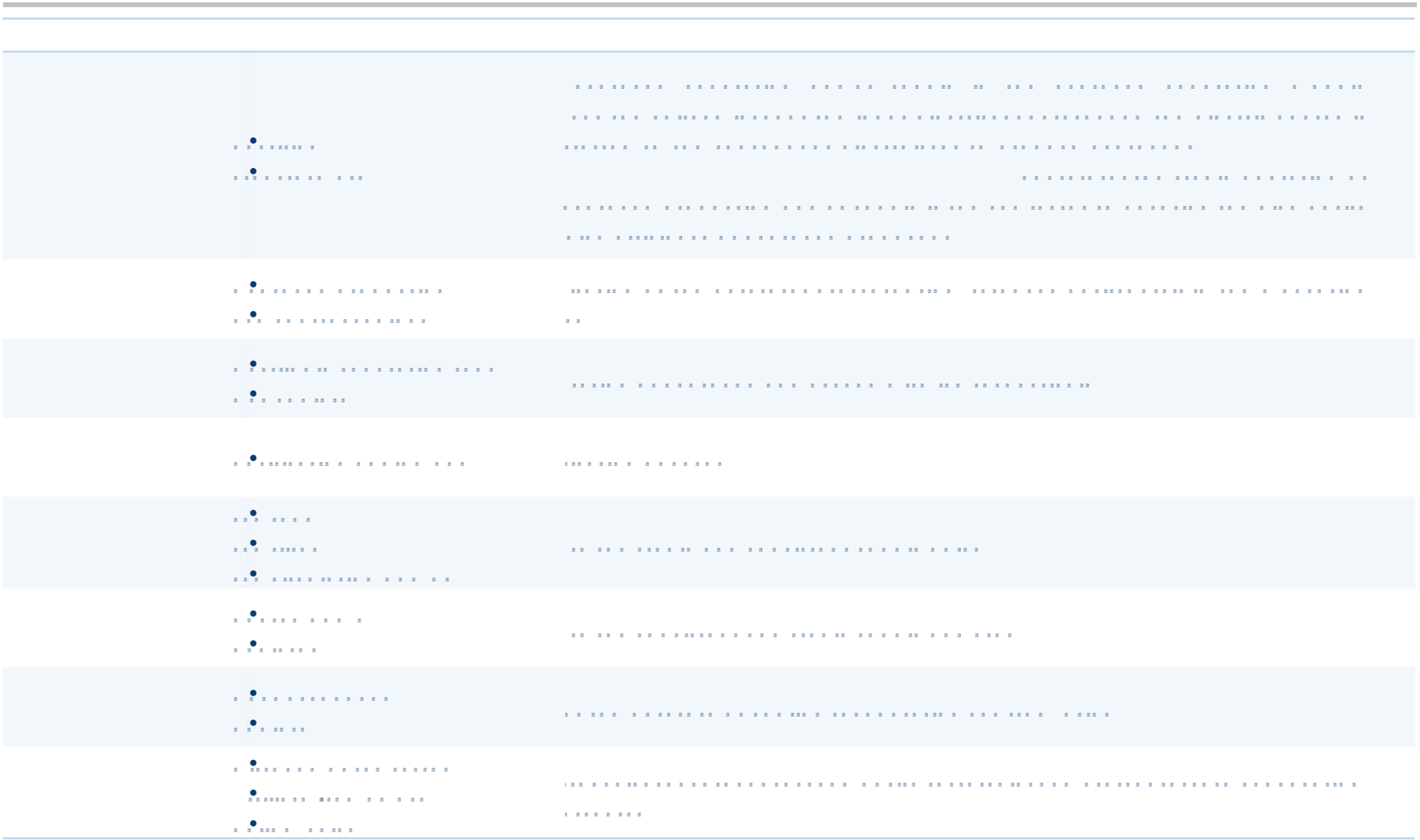

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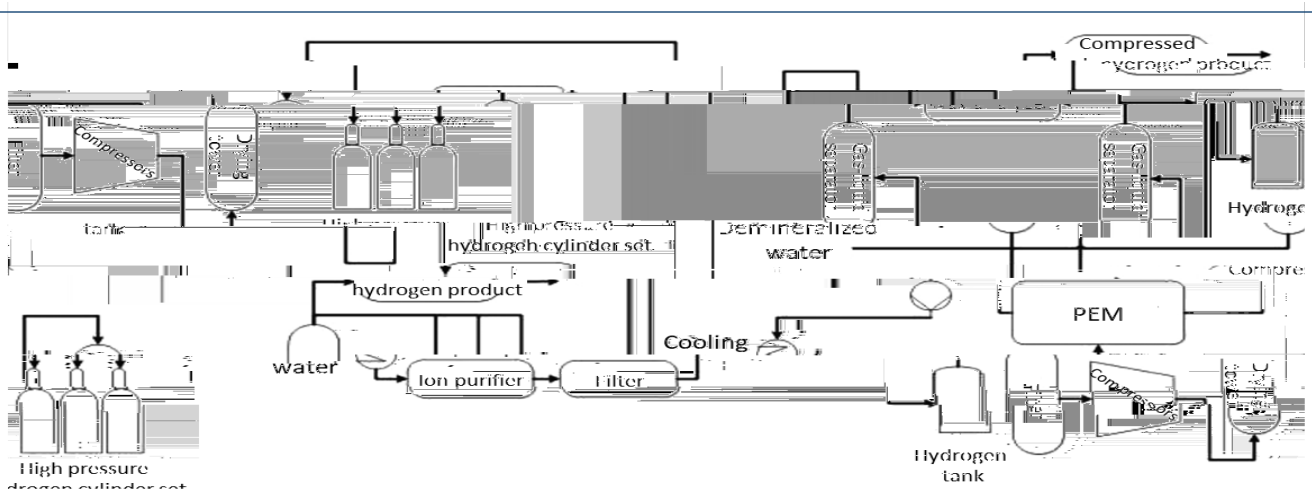

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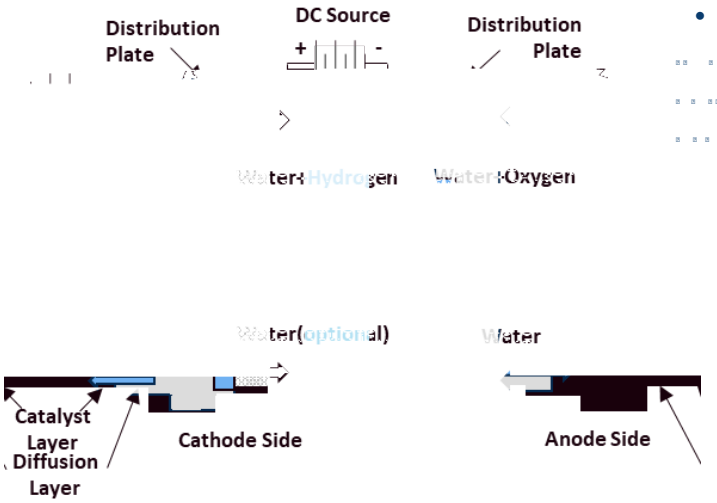

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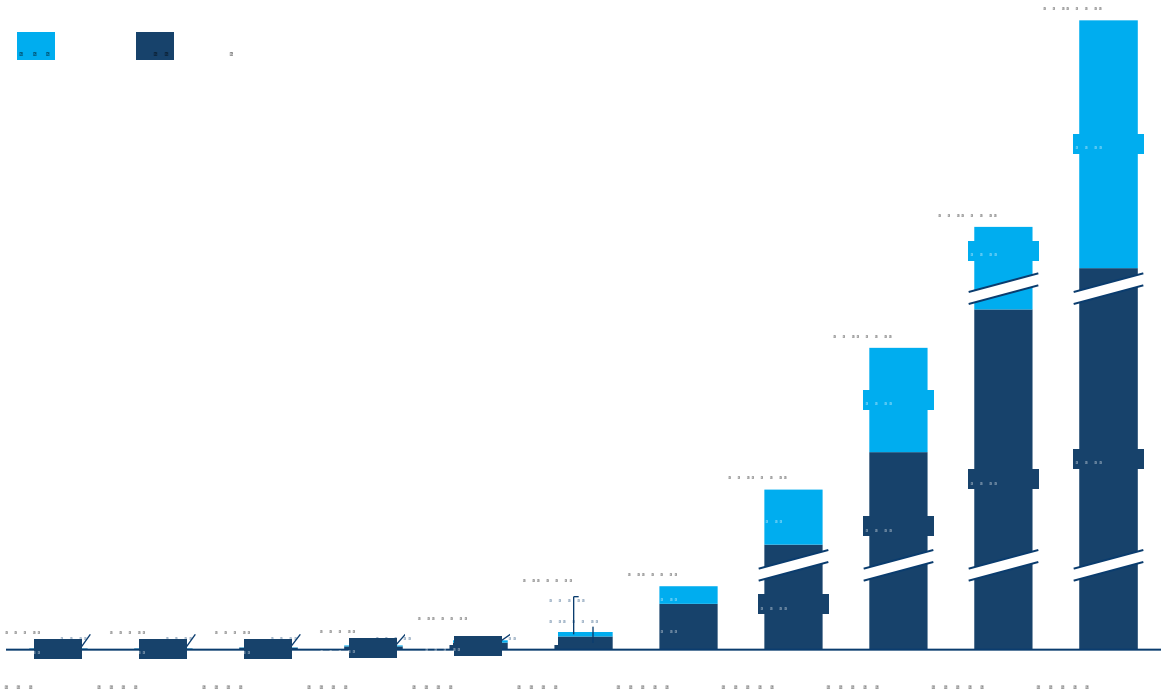
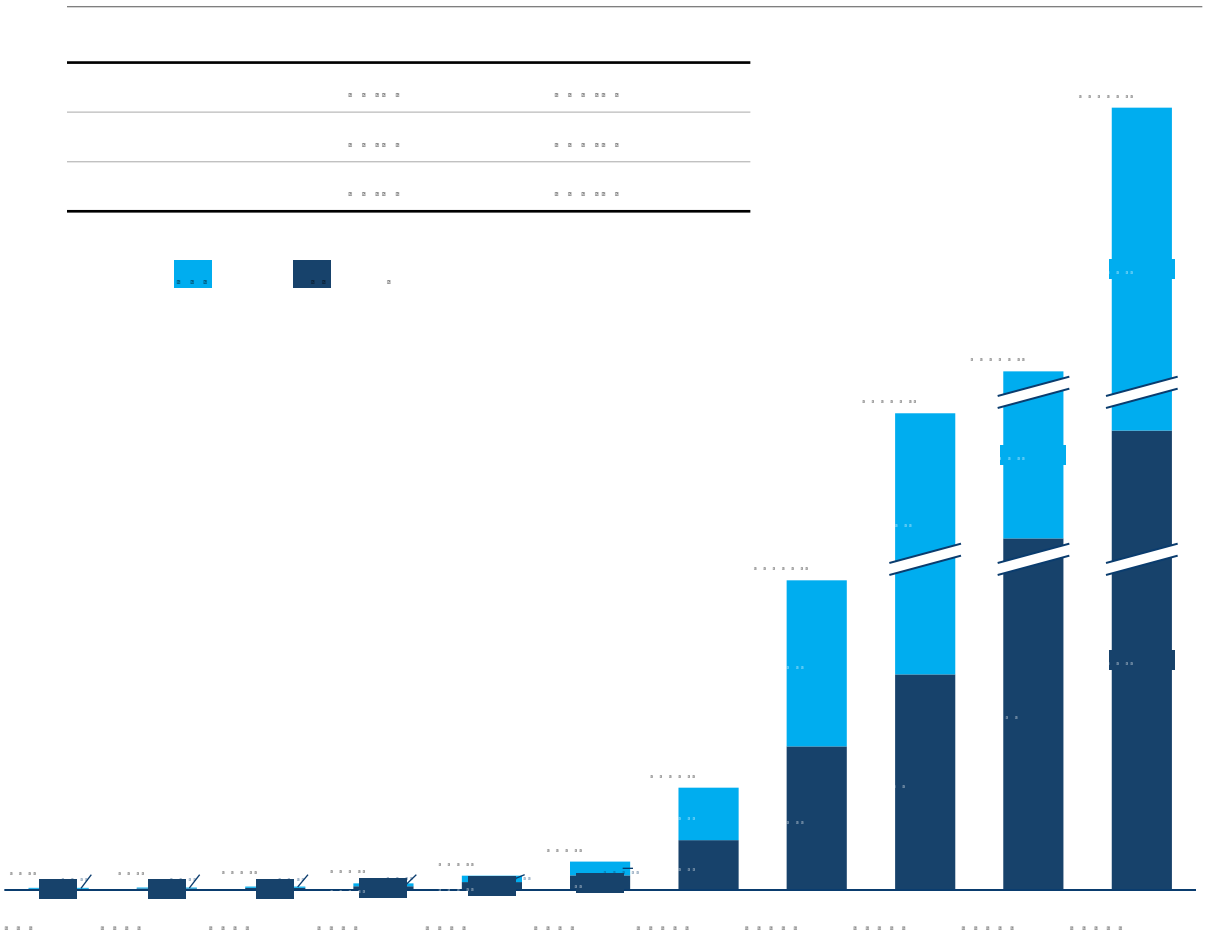
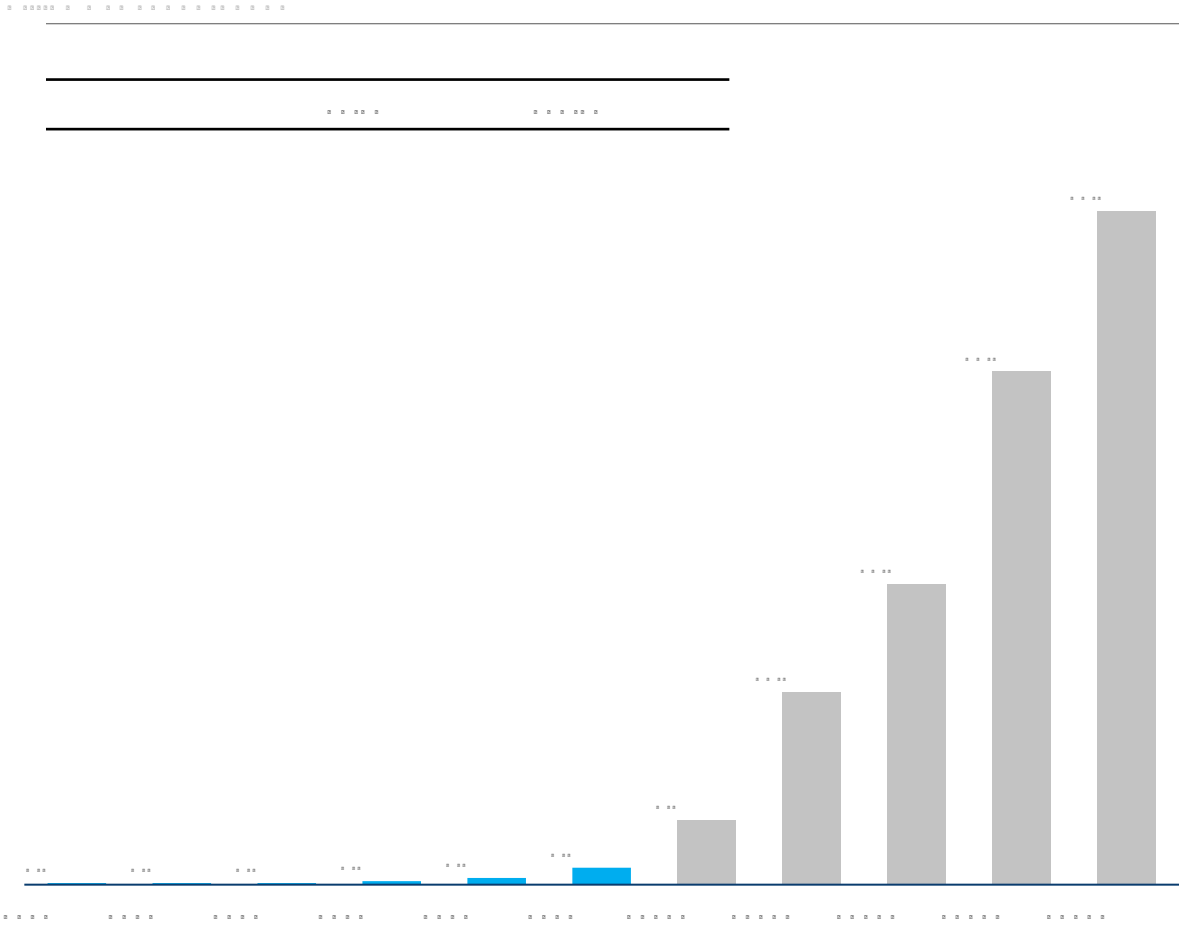


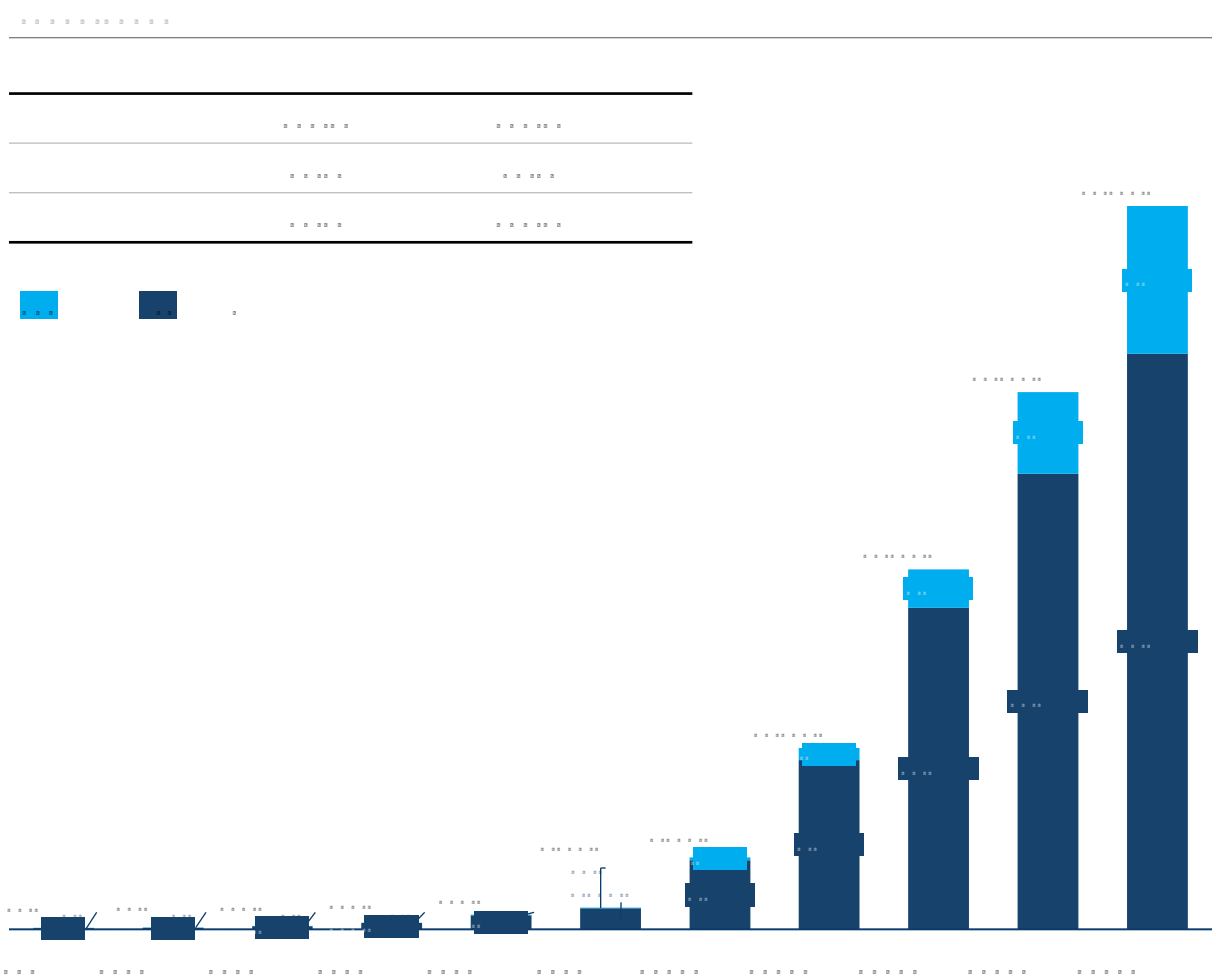
Source: IEA, Policies by different governments, Frost & Sullivan



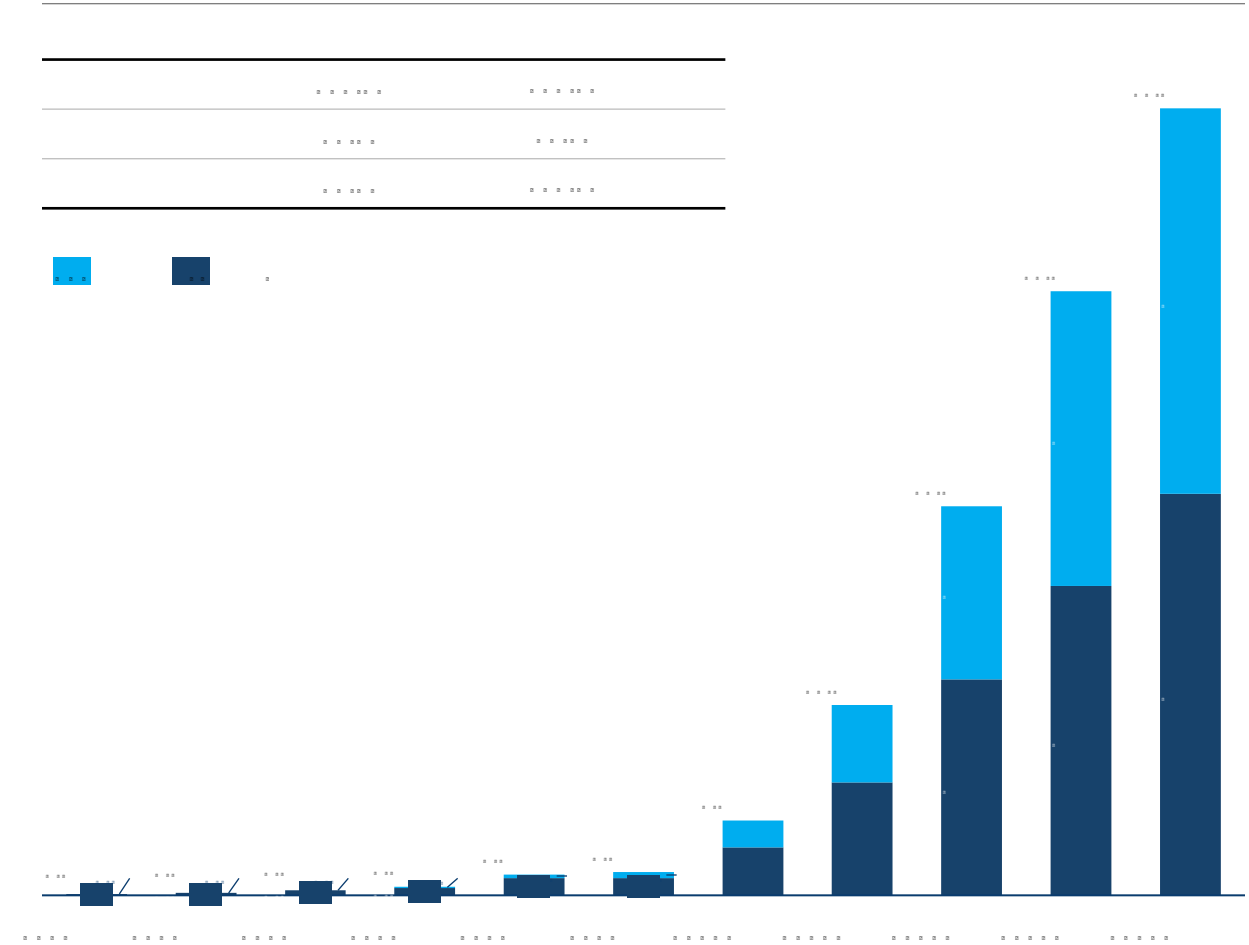
Source: IEA, Policies by different governments, Frost & Sullivan



Source: IEA, Frost & Sullivan

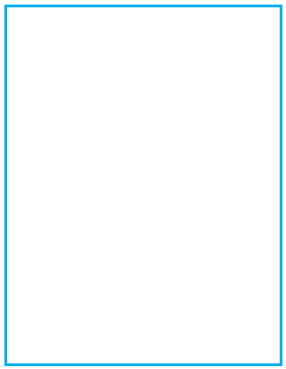


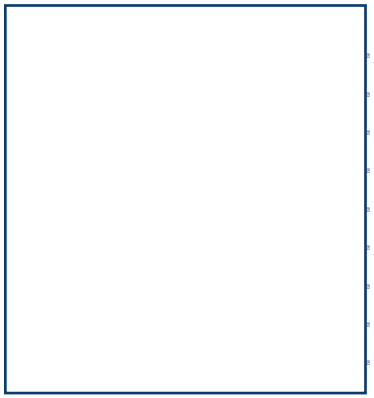
Source: GGII, Frost & Sullivan

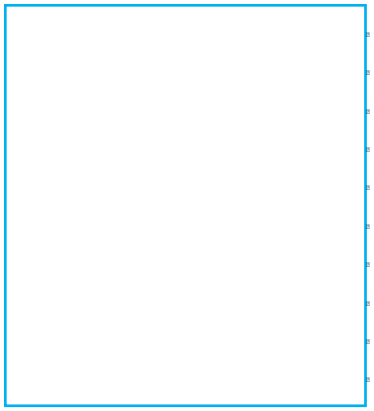


Source: GGII, Frost & Sullivan

SourceIEA,Frost & Sullivan







Source: Frost & Sullivan

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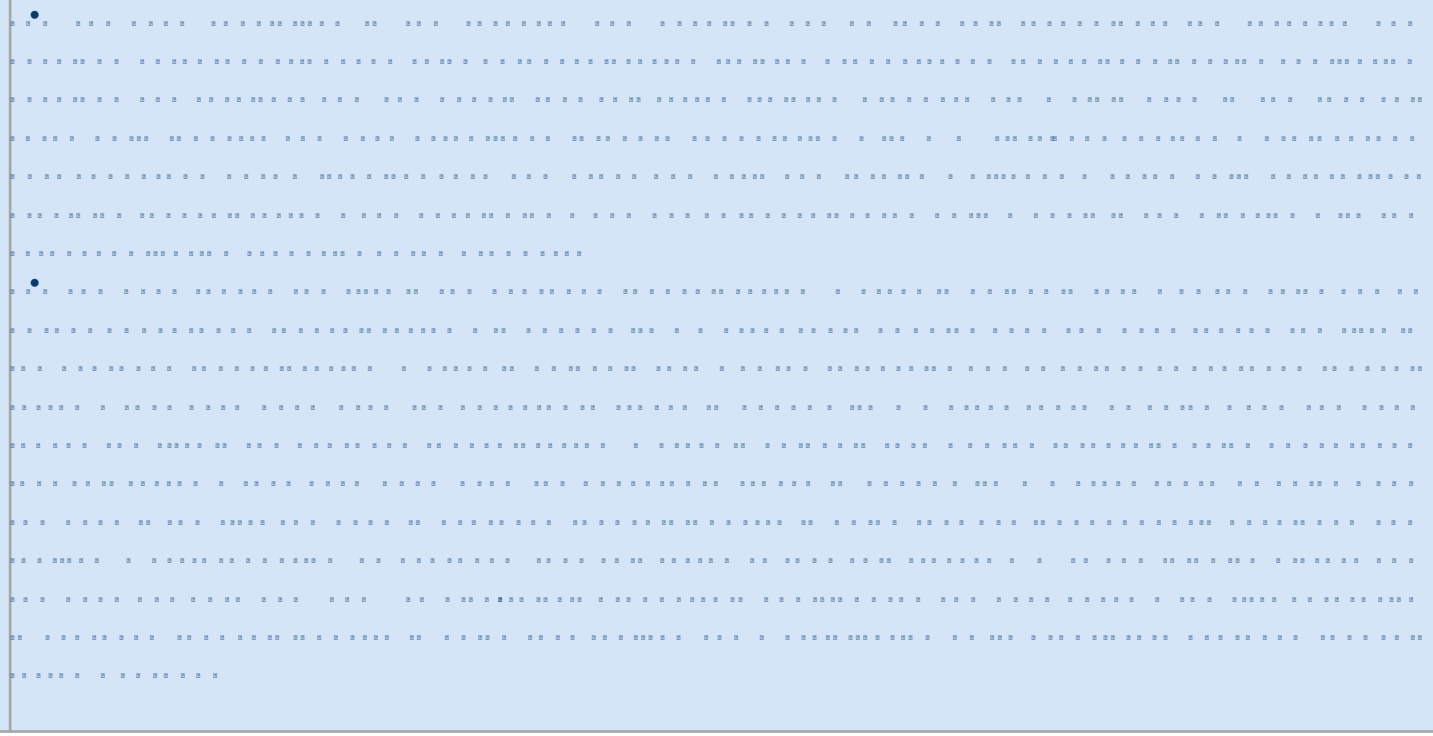
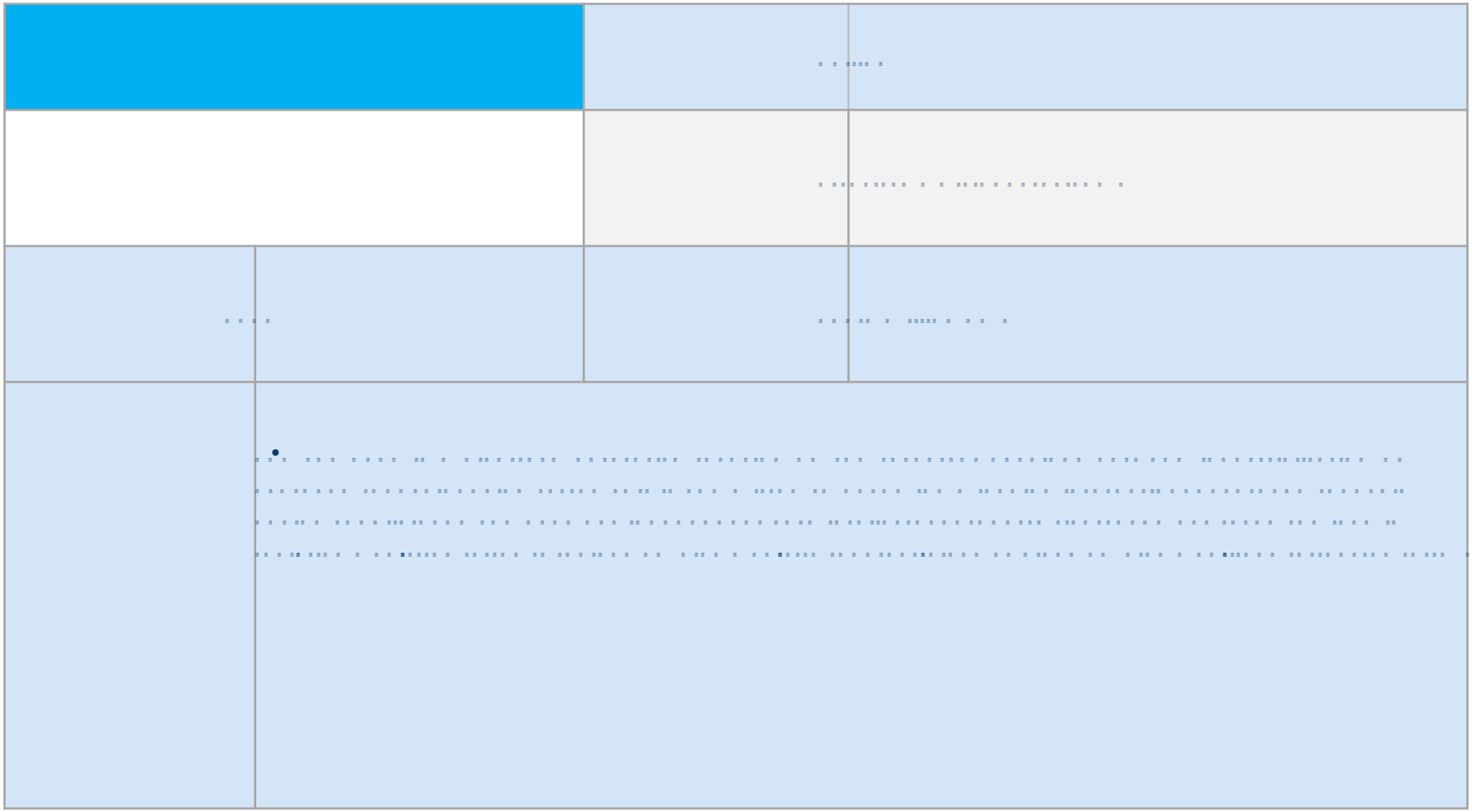


Source: Frost & Sullivan



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Source: Frost & Sullivan

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Source: Frost & Sullivan

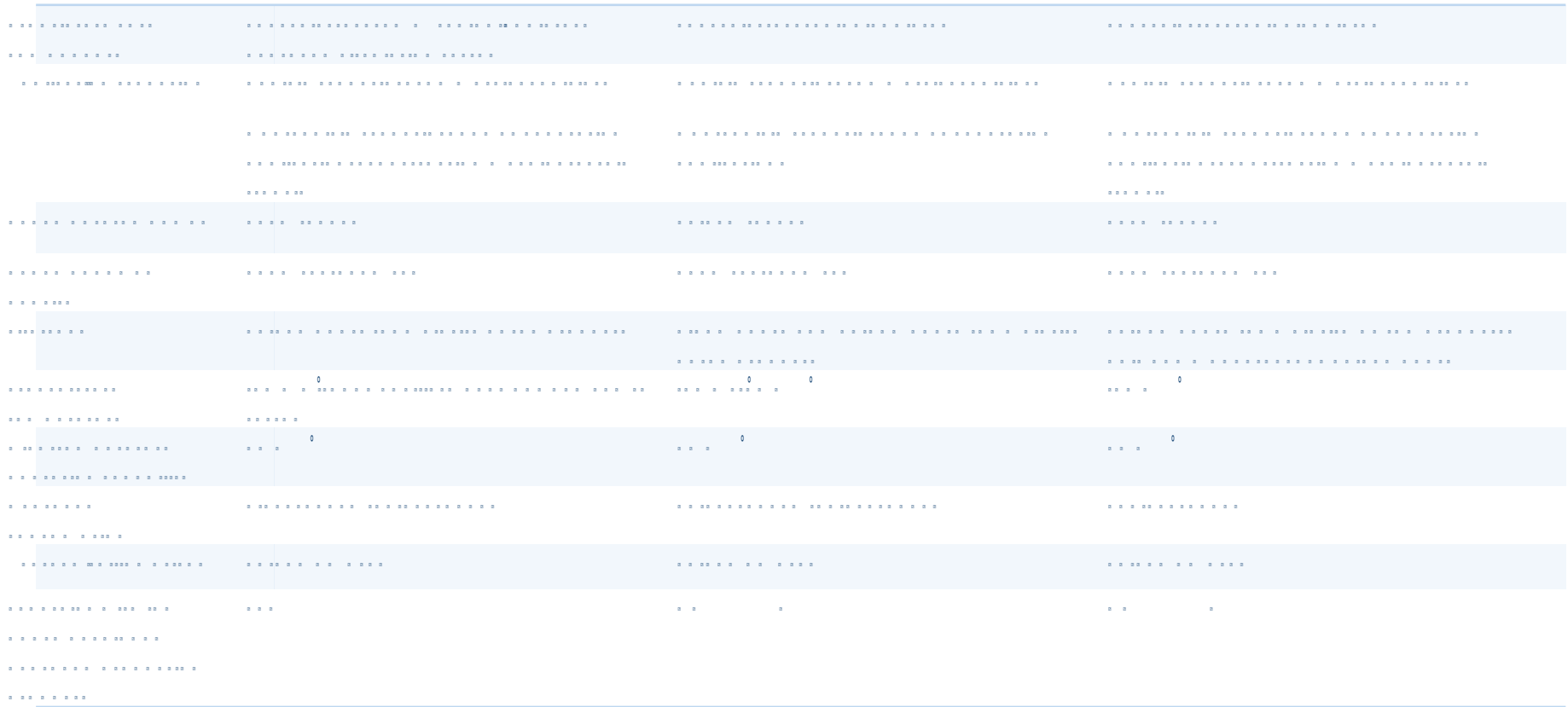
Note: Product Layout here refers that the company has finished products available for sale.

Company G was founded in 2016 and is based in Jiashan, Zhejiang Province. It focuses on developing hydrogen energy equipment in China with its own independent research and development team. Its products include but not limited to fuel cells.
Company H was founded in 2017 and is based in Shanghai. It focuses on the research and development, production, sales and overall solutions of fuel cell stacks.

Source: Frost & Sullivan

Source: Frost & Sullivan

Source: Frost & Sullivan



Notes:(1) The average selling price of fuel cell systems listed here refers to price in 2022; the average selling price of the Company's fuel cell systems refer to price of those incorporating its own fuel cell stacks.(2) Hydrogen consumption listed above refers to related figures for hydrogen fuel cell systems empowering 49T heavy-duty trucks.

Notes: Hydrogen consumption is an indicator influenced by multiple factors, for instance, vehicle types, vehicle weight, power output of the hydrogen fuel cell systems, etc. To assess the performance of hydrogen fuel cell systems, it is reasonable and meaningful to compare hydrogen consumption of the same vehicle type and weight incorporating hydrogen fuel cell systems provided by different companies, than to compare hydrogen consumption of different vehicle types and weight.
As confirmed by Frost & Sullivan, heavy-duty truck is the largest application segment of hydrogen fuel cell systems in 2023. Among heavy-duty trucks in different weights, 49T heavy-duty truck is the most commonly used type, accounted for approximately 40% of all heavy-duty trucks as of the end of 2023.

Source: Frost & Sullivan

Source: Frost & Sullivan

Source: Frost & Sullivan

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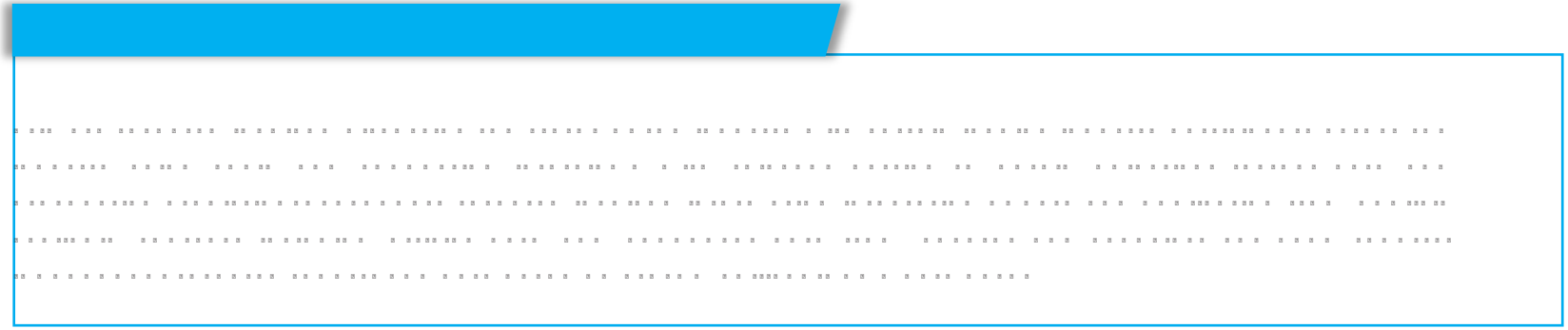

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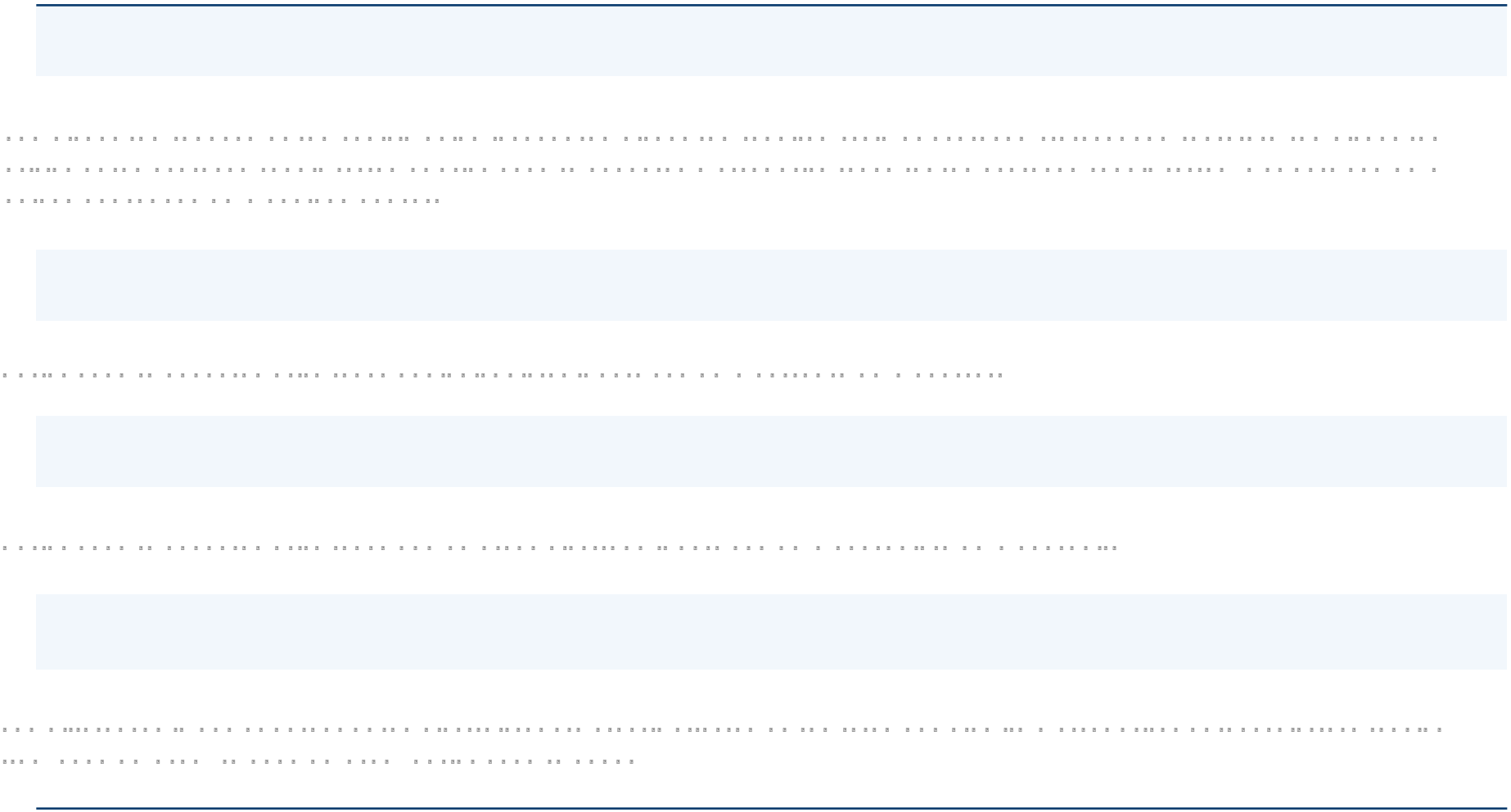
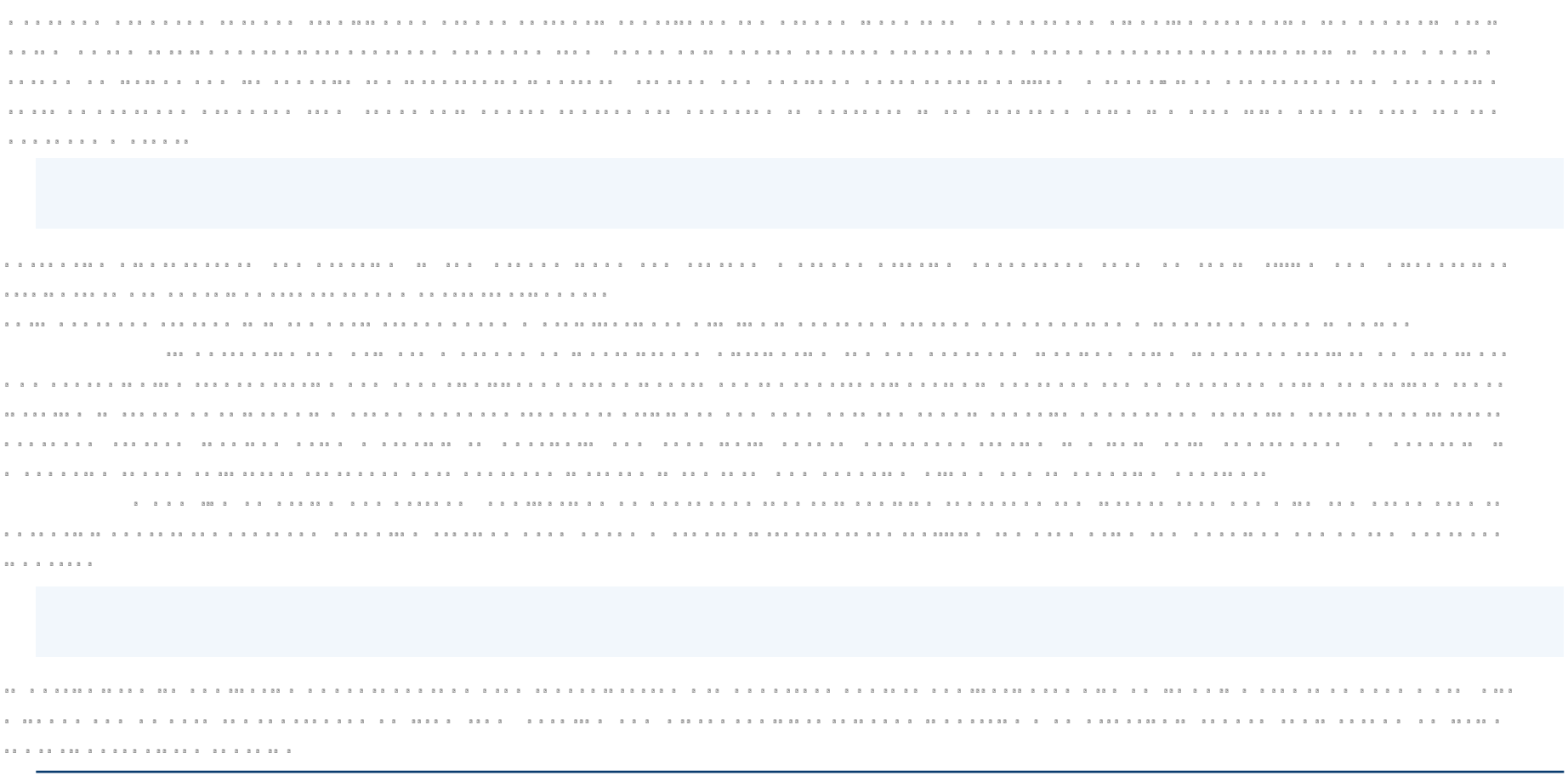
Source: Frost & Sullivan

Source: Frost & Sullivan



Source: Frost & Sullivan



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Source: Frost & Sullivan

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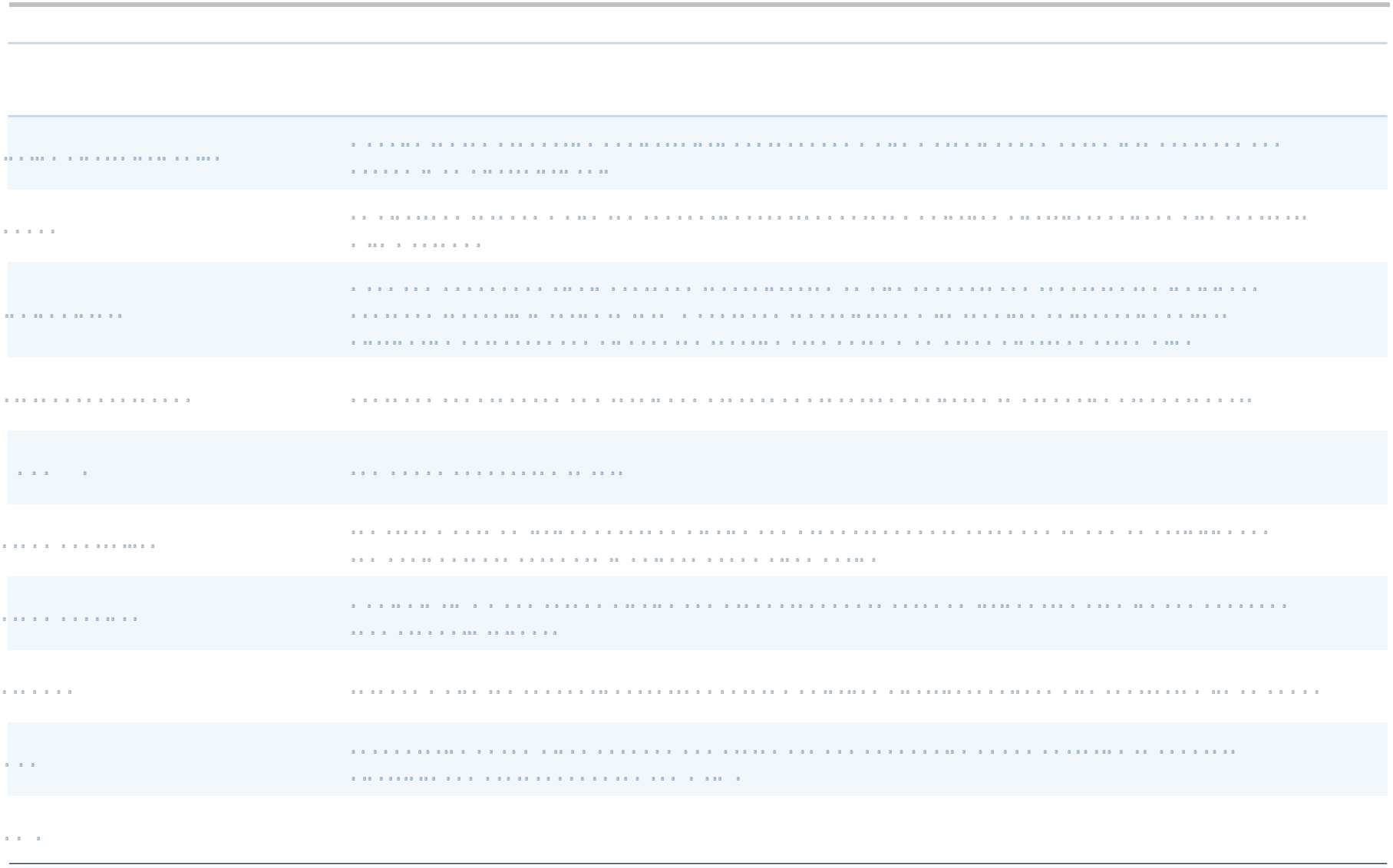
Source: Frost & Sullivan

Source: Hydrogen and Fuel Cell Strategy Council of Japan, Frost & Sullivan

Source: Hydrogen and Fuel Cell Strategy Council of Japan, Frost & Sullivan



Source: Frost & Sullivan

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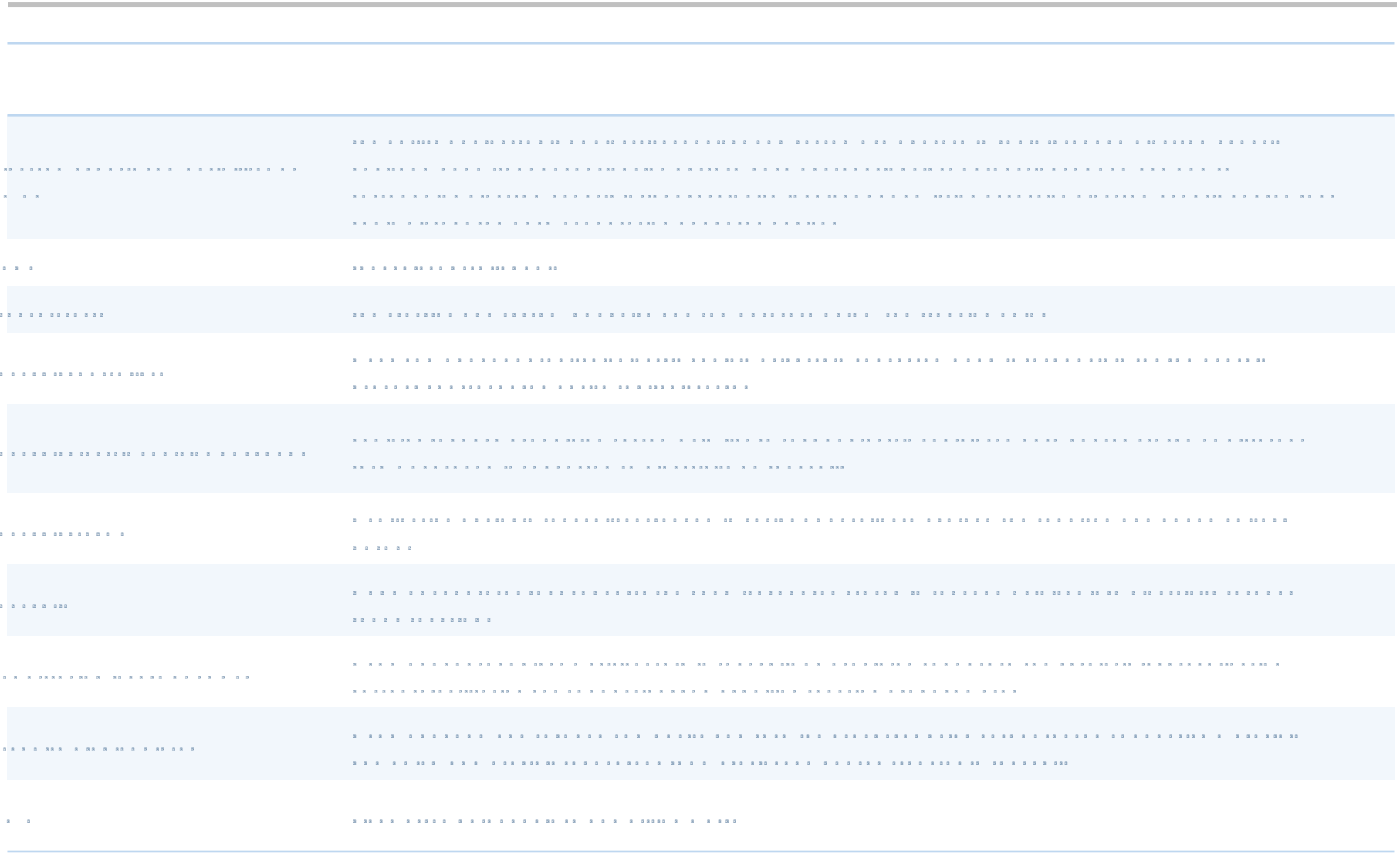
Source: Frost & Sullivan



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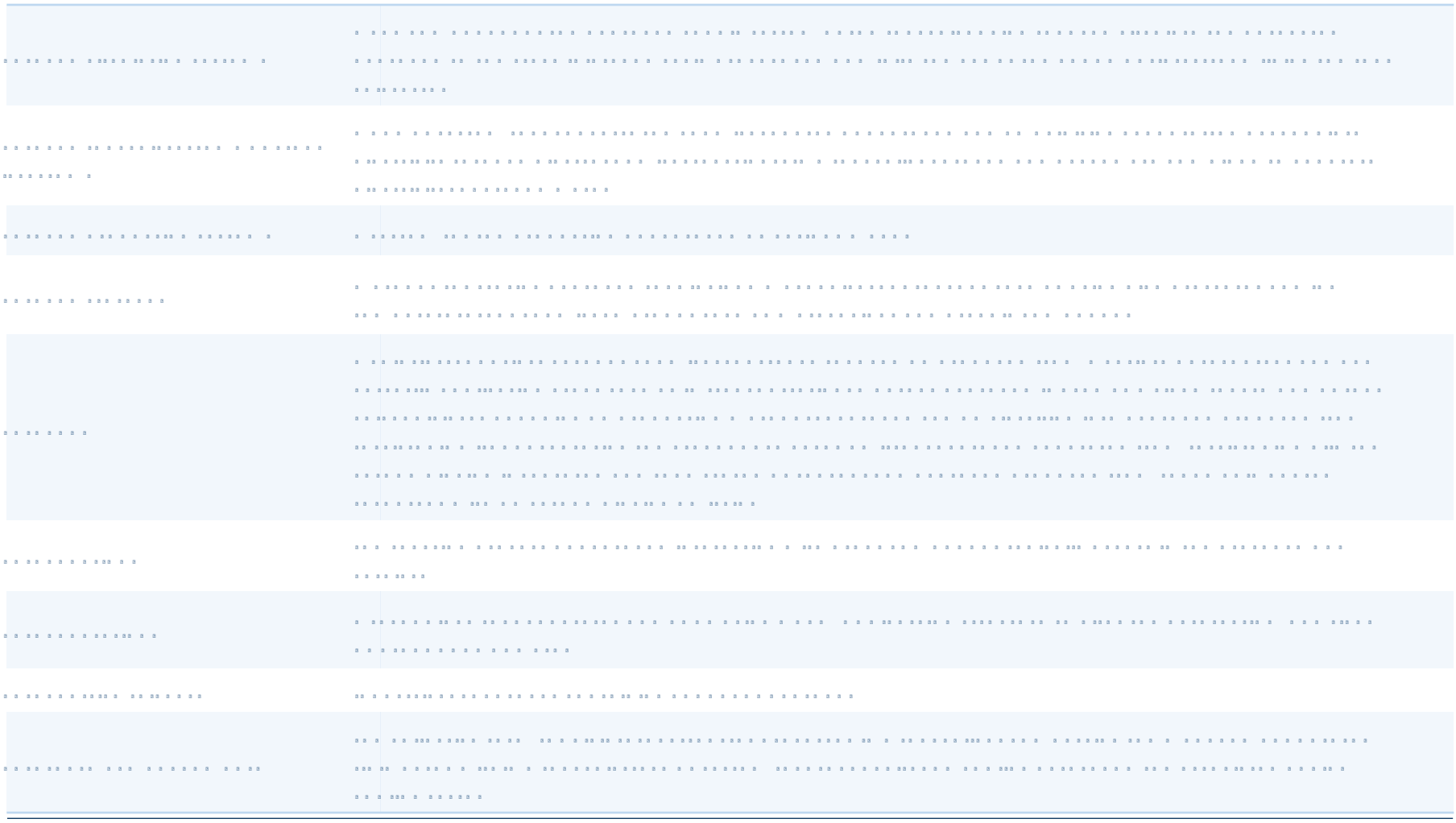

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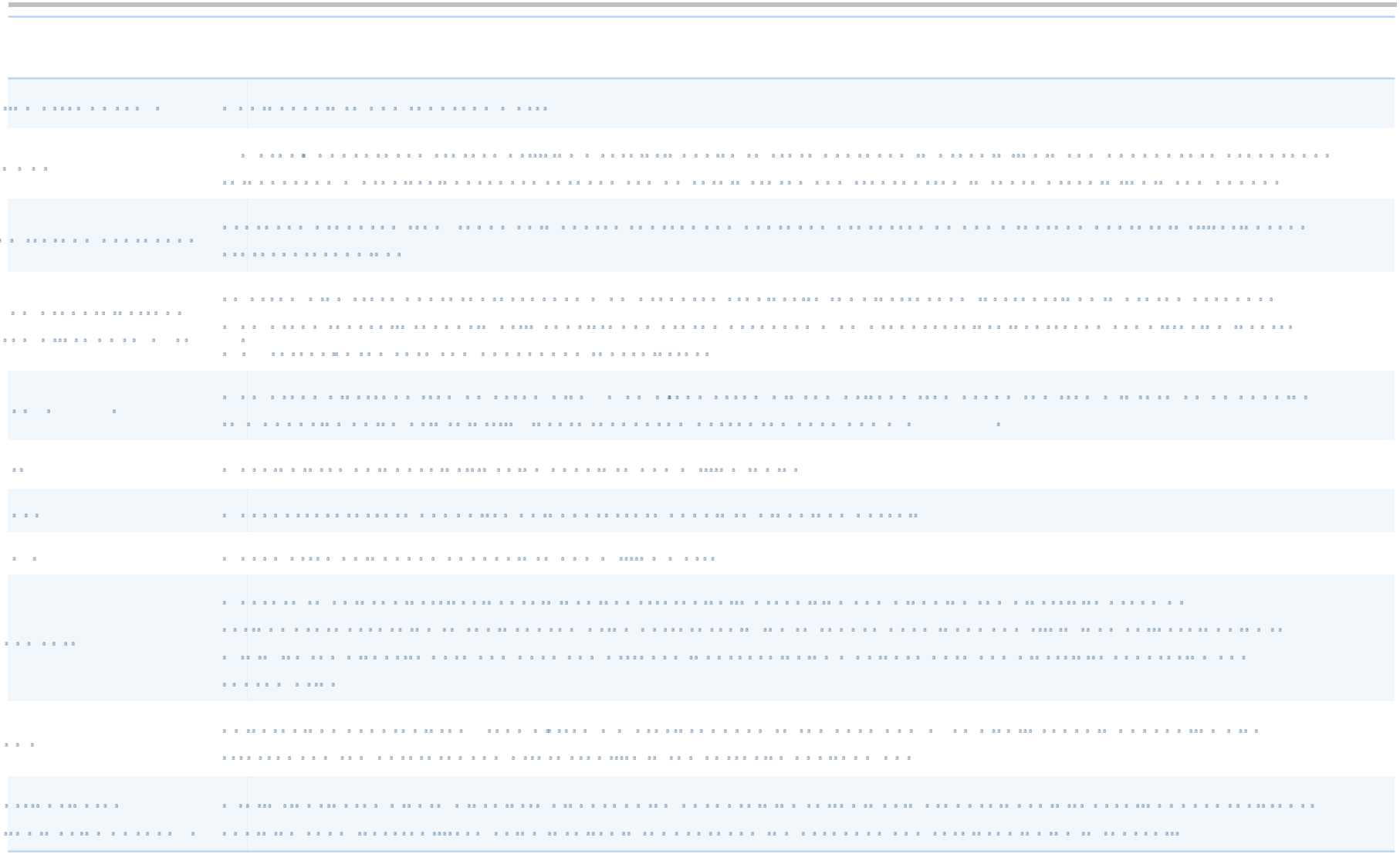

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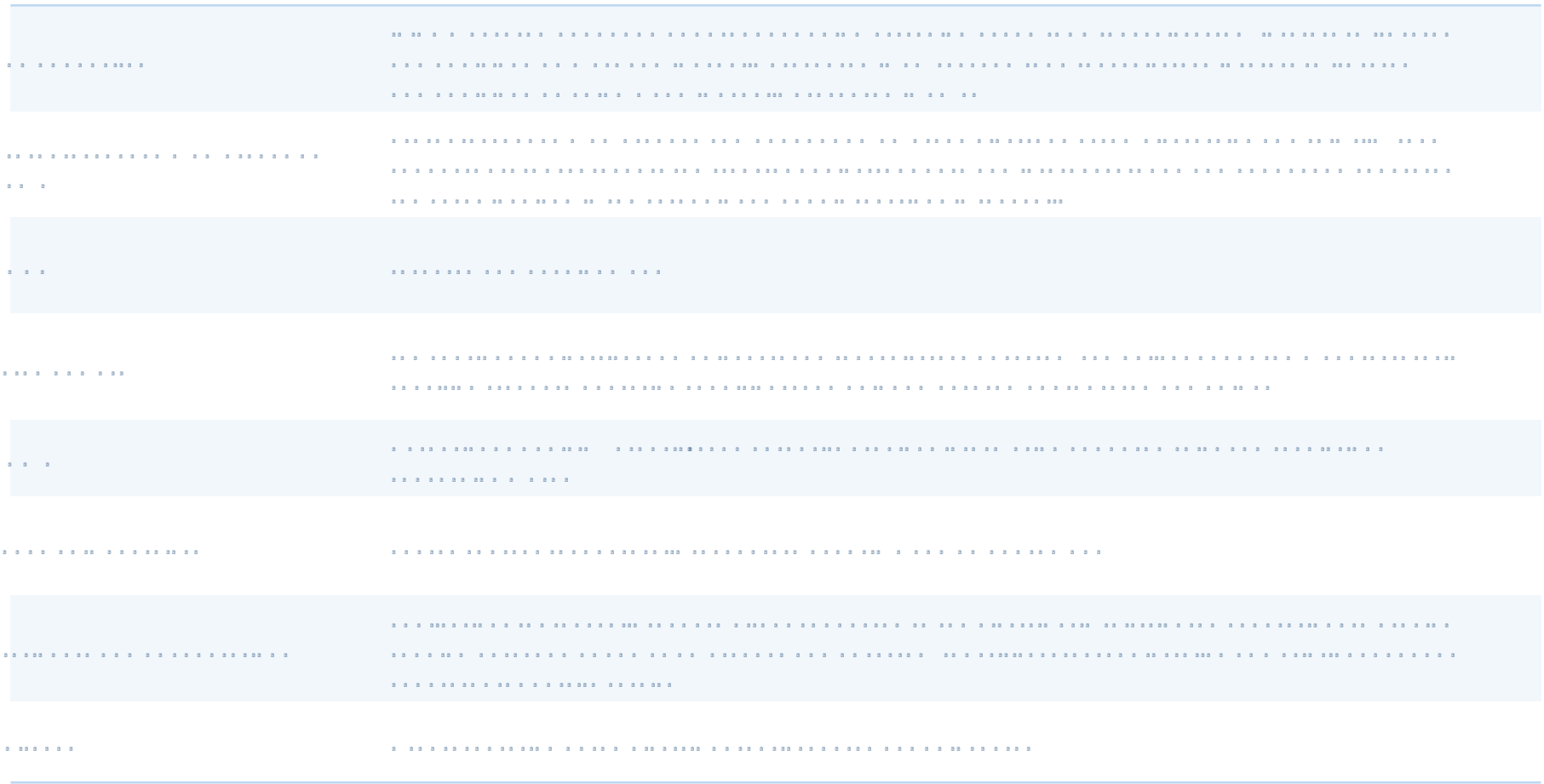
Source: Frost & Sullivan



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Source: Frost & Sullivan

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