The role of Hydrogen in the energy transition

Paul Lucchese, Chair IEA Hydrogen TCP
CEA
Deputy director Capenergies

Electricity system revolution, NEA Workshop, 4th of September 2019, Boulogne France
IEA
A three pillar organization

“the IEA’s unique positioning as the only organisation that covers the full energy mix, enabling a holistic perspective on developments and their implications at a time when the global energy system is transforming rapidly, with implications both in the medium and long term on energy security”

IEA has a leading role in the international energy landscape

PARIS Secretariat Team (300 people) led by Fatih Birol
A referent expert in Energy analysis Scenarios
Plus advisory or strategic bodies

Network of 39 TCPs
6000 expert’s network

Renewables, Smart Grid, oil gas, CCS, Hydrogen, Fuel cells, Electric vehicle, combustion, ICE, Fusion, Heat and Cooling, storage, heat pump…

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AN INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME
IEA Hydrogen TCP
29 members
Singapore, Portugal, Canada and Thailand in advanced discussion...

European Commission
Dr Beatriz Acosta-Ibora
UNIDO (UN)
Dr Federico Villatico-Campbell

Hydrogen Council
Mr Guillaume de Smedt

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Mr Guillaume de Smedt

ExCo: 21 Countries + European Commission + UN + 6 Sponsors + 1 CP in accession

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IEA Hydrogen TCP Tasks – 2015-2020

41 tasks approved in whole or part to date – production is most frequent task topic

<table>
<thead>
<tr>
<th>NR</th>
<th>NAME</th>
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<th>17</th>
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<td>Large Scale Hydrogen Delivery Infrastructure</td>
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<td>LOCAL H2 Supply For Energy Applications</td>
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<td>BioH2 for Energy &amp; Environment (Successor to Task 21)</td>
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<td>Safety (Successor to Task 31; extended 3 years through 2021)</td>
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<td>Power-to-Hydrogen and Hydrogen to X</td>
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<td>Hydrogen in Marine Transport</td>
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<td>Analysis and modeling – a reference database (likely to become a “standing task”)</td>
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<td>i</td>
<td>Market Deployment and Pathways to Scale</td>
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<td>Biological production &amp; conversion of H2 for energy and chemicals (Successor Task 34)</td>
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<td>iii</td>
<td>Hydrogen Export Supply Chains</td>
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<tr>
<td>iv</td>
<td>Hydrogen Applications In Primary Sectors (agriculture, mining and resource)</td>
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<td>In definition</td>
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<tr>
<td>v</td>
<td>Successor tasks for renewable electrolysis, photoelectrochemical water-splitting (PEC), and solar thermochemical hydrogen production</td>
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<td>vi</td>
<td>Industrial Use of Hydrogen in Middle Income Developing countries</td>
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</table>

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AN INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME
Why Hydrogen in energy transition?
Why Hydrogen?

- To get rid off the oil & Gas dependency
- To eliminate local pollutants
- To decarbonize mobility sector, industrial sector and others and limit global warming proven that Hydrogen is CO2 free or low carbon
- To integrate more renewables and procure flexibility in the new energy system
After 3 years stabilization period, CO2 emissions are going up again

Fatih Birol Executive Director IEA

Despite impressive growth in Variable Renewables Deployment (< 1000GW PV+Wind) ...

but for < 1 % World final energy consumption

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Variable Renewables have to face big challenges to penetrate two hard-to-abate sectors: Transports and industry.

Source: IEA 2DS scenario, Renewables Division Report, 2017, IEA
Unprecedented Momentum for Hydrogen since 2 years…

World Governments

• 2015 COP21 Paris Agreement
• 2017 Davos 2017: Creation of Hydrogen Council
• 2017 Japanese Prime Minister announces Japan’s intent to become world’s first hydrogen society
• 2018 Hydrogen adopted as 8th MISSION INNOVATION Challenge in May
• 2018 European Ministries – Linz Declaration on Hydrogen in September
• 2018 IPCC Special Report on Global Warming of 1.5° C in October; hydrogen workshop in October
• 2018 Japan makes voluntary contribution to IEA for preparation of G20 Report on Hydrogen to be delivered June 2019 at G20 Meeting
• 2018 First Hydrogen Ministerial Meeting in Japan in October produces “Tokyo Statement”
• 2019 FCH2JU Study Hydrogen Roadmap Europe – published in February
• 2019 Hydrogen Initiative at CEM, Vancouver
• 2019 Delivery of IEA Hydrogen Report at G20 Meeting in June with strategic workshop
• 2019 2nd Hydrogen Ministerial Meeting in fall
What could bring Low Carbon hydrogen: Focus on 3 sectors

• Industry:
  – *Decarbonise hard-to-abate sectors* such as steel, chemicals etc...

• Transport
  – *Hydrogen as a gas for Fuel cells vehicle: trucks, train, passenger cars, LDV, boats, buses, coaches, boat*
  – «Green Hydrogen inside » for liquid or gaseous fuel: Electrofuels, synfuels, biofuels, synthetic methane....

• Energy grids: gas, electricity and heat
  • *Hydrogen and fuel cells for stationary applications*
  • *Hydrogen in the gas grid (pure or mixture)*
  • *Integrate more renewables*, including by enhancing storage options & tapping their full potential
  • *Enhance energy security* by diversifying the fuel mix & providing flexibility to balance grids
Hydrogen production
Transport and distribution
TODAY: Hydrogen from fossils with a lot of CO2 emissions

1 ton of H2 emits 9-10 tons of CO2 !!! Total 800 Mt CO2 emitted by Hydrogen production (more than France emissions)
Equivalent to 258 GW HHV and CO2, 2% world Emissions with 10% growth

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Perspectives for Hydrogen production

Source: US DOE/EERE

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Hydrogen production costs

Virtually all hydrogen today is produced using fossil fuels, as a result of favourable economics. In countries reliant on gas imports but with good renewable resources, hydrogen production from renewable electricity can be cost-competitive with production from natural gas.
Massive and low cost Hydrogen production from Renewables in some areas

The declining costs of solar PV and wind could make them a low-cost source for hydrogen production in regions with favourable resource conditions.

Source IEA, 2019
The future of Hydrogen, Webinar

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AN INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME
Optimal cost versus duration

Electrolytic hydrogen production cost at different full load hours

Hydrogen costs from
- Electricity use
- CAPEX+OPEX

Source IEA, 2019
The future of Hydrogen, Webinar
HYDROGEN Production, Transport and Distribution mastered by industry

- **Hydrogen Production**
- **Hydrogen Distribution & Delivery**
- **Hydrogen recovery Technologies**
- **Hydrogen Storage**
- **Road Transport**

**Hydrogen Infrastructure: Supply Chain of H2**

- Liquefaction
- Compression
- Transport pipeline
- 1100 kms pipe
- 12 hydrogen pipeline networks

**HYDROGEN Production, Transport and Distribution** mastered by industry

**Hydrogen**

- Production
- Distribution & Delivery
- Recovery
- Transport
- Storage

- **Compression**
- **Liquefaction**
- **Transport**
- **Storage**

**AN INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME**

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Different options for long distance hydrogen transport

- **Collection**: Pipeline, truck
- **Transmission**: LNG ship, truck, pipeline
- **Distribution**: Pipeline, truck
- **Demand**: Industry, buildings, transport, power generation

- Hydrogen gas
- Liquid hydrogen
- Ammonia
- LOHC

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Japanese scheme to import Hydrogen from different countries

Establishing an Inexpensive, Stable Supply System

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A new and emergent topic: international trade for hydrogen

What could be the new roads of hydrogen

Renewable hydrogen production –
Global perspective

- Due to location boundaries, Germany will have the demand for energy import
- High potentials for RE offer the opportunity for green PtX with competitive prizes
- Enable regions to be self-sufficient in energy and potentially chemical feedstocks
  → Global transport infrastructure
- PtX offers the opportunity of versatile, scalable, intelligent and flexible system integration with high shares of RE

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Industry

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Chemical products, Refinery with green hydrogen

Source IEA, 2019
The future of Hydrogen, Webinar

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Hydrogen routes for steel production are emerging, but expensive

The hydrogen-based DRI-EAF route is between 10% and 90% more costly than its natural gas-based counterpart, and is highly sensitive to the cost of electricity.
Transport and mobility
Advantages of a Fuel Cell Electric Vehicle FCV for intensive or heavy use

- **System cost**
  - FCV: System cost increase for longer cruising distance is relatively small - It is advantageous in mid-to-long-drive-range applications

- **Cruising range**
  - EV: System cost is relatively high for longer distances
  - FCV: System cost is relatively low and remains consistent over longer distances

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FC: some key advantages

A HRS is able to refuel ~15 times more vehicles than a fast charging station, leading to significantly less space requirements and offsetting the higher installation costs of a HRS.

**Refueling speed**

<table>
<thead>
<tr>
<th>Source</th>
<th>Hydrogen Europe @E4SM Conference, Marseille 2019 Capenergies/GreenUnivers TM</th>
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<table>
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<tr>
<th>Speed (Km/15 minutes of refueling)</th>
<th>~1,875</th>
<th>~1,375</th>
<th>~90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
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<tr>
<td>HRS</td>
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<tr>
<td>Fast charger</td>
<td>x15</td>
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</table>

**Space requirements**

- ~8 MW powerline required for 60 fast chargers to cover peak load from chargers while hydrogen can use flexible renewable energy.

1 HRS with 4 dispensers replaces 60 fast charger stations.

**Investment costs per refueling EUR/refueling**

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<tr>
<th>Source</th>
<th>Hydrogen Europe @E4SM Conference, Marseille 2019 Capenergies/GreenUnivers TM</th>
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<tr>
<th>Cost</th>
<th>~7.6</th>
<th>~3.6</th>
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<tbody>
<tr>
<td>Petrol</td>
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<tr>
<td>Hydrogen refueling station</td>
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<tr>
<td>Fast charger</td>
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</table>

Hydrogen refueling is 15x faster than fast charging.

Hydrogen refueling is half as capital-intensive as fast charging.

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12,000 cars 400 Refuelling stations Hydrogen is there but slowly increasing
light Duty- Passenger Cars & Captive Fleets; Heavy Transport on Land - buses, heavy duty trucks, light rail trains, logistics/utility vehicles; Maritime and Air; Portables

**Passenger Cars & Captive Fleets**
- Toyota Mirai
- Honda Clarity
- Hyundai Tucson
- Hyundai Genesis
- Japanese vehicle production increases dramatically.
- FCEV registration is now being tracked in California.
- Norway anticipates application of FCEVs incentives similar to BEVs.

**Buses**
- UC Transit in Oakland, CA, USA - largest fleet in North America, with 12 fuel cell buses.
- Foshan and Yunfu – $17 million order for 300 fuel cell buses.
- European Union Coordination a national Call for order in progress for a 1000 FC Buses
- South Korea - planning to replace 27,000 CNG buses with FC buses by 2030.

**Heavy Duty Trucks**
- Nikola Motor Company H2 powered long range tractor trailer
- Toyota a heavy duty drayage vehicle (class 8), Amazon buying $70 million of fuel-cell forklifts.

**Light Rail Trains**
- UPS - first hydrogen fuel cell electric class 6 delivery van. 17 vans in the U.S. by year end 2018.
- In 2017, Alstom unveiled its Coradia iLint, which will replace diesel trains in the extensive, un-electrified sections of rail in Germany.

**Logistics Vehicles**
- Hydrogen-powered Drone
- Fuel cell technologies power drones varied applications from lightweight Hycopter to larger military based applications like the Boeing Insitu's ScanEagle drone.

**Airplanes & Drones**
- Hydrogen-powered Drone
- Fuel cell technologies power drones varied applications from lightweight Hycopter to larger military based applications like the Boeing Insitu’s ScanEagle drone.

**Maritime**
- 90% of all trade is by ship. Maritime tourism is huge global industry.
- The Red and White Ferry Company and Sandia National Laboratory have teamed up on a feasibility study for designing, building and operating a high-speed hydrogen fuel cell powered passenger ferry and refueling station.

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BUT HYUNDAI WAS THE FIRST TO INTRODUCE A HYDROGEN CAR ON THE MARKET!

December, 4th, 2015:

a start up Company, STEP, launches the first taxi fleet only with Hydrogen cars in Paris center:
100 ix35 FC Hyundai now
Air Liquide provides the 4 Hydrogen refuelling station

If you go to Paris you could take a hydrogen taxi!
For long term perspective: equivalent cost for both BEV and FCEV

Total costs of ownership could break even with EVs at 400 km drive range. Prospects for fuel cell cars depend on cost reductions in fuel cells and storage tanks, and the utilisation of stations.

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« Green Hydrogen inside » fuels

Electro fuels: a broad definition

<table>
<thead>
<tr>
<th></th>
<th>Without carbon</th>
<th>Containing carbon</th>
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<tbody>
<tr>
<td>Gaseous</td>
<td>Hydrogen gas (H₂)</td>
<td>Methane (CH₄)</td>
</tr>
<tr>
<td>Liquids</td>
<td>Ammonia (NH₃)</td>
<td>Alcohols (CₓHᵧOH)</td>
</tr>
<tr>
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<td>Hydrocarbons (CₓHᵧ)</td>
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Biofuels and hydrogen synergies

There is a great diversity of options for electro fuels, all based on hydrogen, which may correspond to different needs and uses.

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AN INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME
Energy Grids
How Hydrogen could absorb excess of electricity from variable renewables?

Power to Gas projects

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By Q1 of 2017, the (realised) installed capacity of electrolyzers totaled approximately 30MW. The vast majority is located in Germany, followed by Spain and the United Kingdom.

More than 60% of the power-to-gas projects have hydrogen (H₂) as final product, 23% methane (CH₄) and 15% both hydrogen (H₂) and methane (CH₄). Only one project produces methanol (CH₃OH).

More than 200 demonstration projects around the world have been announced, with a further 50 projects in operation or near full scale. The projects are located in 13 countries across the world.

In most of the projects the produced gas finds its destination in the natural gas network (33%). The transport sector and power generation as end users are targeted in 25% of the projects. One single project delivers gas to an industrial user.

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Source:
- Hylaw Project FCH JU
- IEA/Hydrogen/Task 38

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JUPITER 1000 project in Fos sur mer (Marseille)
Hydrogen injection into gas grid

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H₂ production cost ranges

Source: C. Cany & all
CEA/I-tésé
WHEC, Zaragoza, Spain, June 13-16 2016
Conclusions
Next steps
Electrolyser become a Key Technology for energy transition

Challenge: Scale up

Installed electrolysis capacity for PtG/PtL in scenarios for Germany in GW

- Scale and learning effects are critical for cost reduction, but uncertain (e.g. CO₂ from air).
- International 100-gigawatts-challenge.
- Investments are not to be expected without political intervention or high CO₂ price due to high cost of synthetic fuels.

Own illustration based on Frontier Economics (2018) and others

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7 recommendations from IEA

• Establish a role for hydrogen in long-term energy strategies
• Stimulate commercial demand for clean hydrogen
• Address investment risks for first-movers
• Support R&D to bring down costs
• Eliminate unnecessary regulatory barriers and harmonise standards
• Engage internationally and track progress
• Focus on four key opportunities to further increase momentum over the next decade

Source IEA, 2019
The future of Hydrogen, Webinar
4 opportunities for scale up
Coastal industrial clusters: Gateways to building hydrogen hubs

Industrial clusters are places where existing uses of hydrogen can be leveraged as sources of demand for new hydrogen production facilities and CCUS without extensive new infrastructure.

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Source: IEA, 2019
The future of Hydrogen, Webinar
Hydrogen Council Vision

Enable the renewable energy system → Decarbonize end uses

1. Enable large-scale renewables integration and power generation
2. Distribute energy across sectors and regions
3. Act as a buffer to increase system resilience
4. Help decarbonize transportation
5. Help decarbonize industrial energy use
6. Help decarbonize building heat and power
7. Serve as renewable feedstock

SOURCE: Hydrogen Council

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Nuclear and hydrogen

- Past R&D on thermochemical cycles, High temperature electrolyser etc....

- Holistic approach of smart electric grid with load based nuclear plat and VRE

- **Example of France:** New challenges for Nuclear in France Installed nuclear base
  - Decrease of the nuclear load factor
  - Increasing needs for flexibility

- New nuclear, SMR etc... integration in a smart energy system

Needs for new economic tools, new studies and needs for international collaboration
NUCLEAR AVAILABLE VOLUME TO PRODUCE HYDROGEN (1/3)

Source C.Cany&all
CEA/l-tésé | WHEC, Zaragoza, Spain, June 13-16 2016
UTILISATION RATE OF THE ELECTROLYSERS (2/3)

Source: C. Cany et al.
CEA/I-tésé | WHEC, Zaragoza, Spain, June 13-16 2016
LEVELISED PRODUCTION COST OF HYDROGEN (3/3)

Source: C.Cany & all, CEA/I-tésé | WHEC, Zaragoza, Spain, June 13-16 2016
The strategic Hydrogen advantages

Hydrogen can play a transformative role as a highly flexible energy carrier during the clean energy transition and in an integrated future multi-sector energy system as follows:

- For Sector coupling - as a bridge between different types of energies
- For Storage – utilizing electrical energy that would otherwise have been lost
- For Storage – enabling use of massive quantities of renewable energy
- For Stability - balancing grid and buffering energy system
- For feedstock – using captured carbon
- For certainty – avoiding CO2 capture from air
- For mobility: allows to decouple high peak of power to utilization and to avoid to overdesign electric grid

Challenges

- Overcome funding issue on investment especially on Mobility infrastructure
- Scale up for manufacturing
- Scale up on Projects and deployment
- New business model to develop to take account complexity of hydrogen role
- Public acceptance

Hydrogen and Nuclear Energy synergies:
initiate international work through a new task inside the framework of IEA Hydrogen TCP with NEA and others?

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Thank you for your attention

Paul.lucchese@cea.fr
BEV and FCEV: complementary depending on needs

FCEVs as most efficient decarbonisation level for long-distances and heavy payloads

- Bubble color representing FCEV or synfuel application of H₂
- Bubble size roughly representing the annual energy consumption of this vehicle type in 2050

Most attractive for

<table>
<thead>
<tr>
<th></th>
<th>BEV</th>
<th>FCEV</th>
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<tbody>
<tr>
<td>Airplanes/freight ships — synfuels based on H₂ as only feasible decarbonization option</td>
<td></td>
<td>n/a</td>
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<tr>
<td>Passenger ships</td>
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<tr>
<td>Medium and heavy truck segments, by attractiveness for FCEV vs. BEV</td>
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<tr>
<td>Long-haul freight (coast to coast)</td>
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<tr>
<td>Mining</td>
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<tr>
<td>International road masters</td>
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<tr>
<td>Regional distributor (high payload)</td>
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<tr>
<td>Regional distributor (low payload)</td>
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<tr>
<td>Local drop and drive</td>
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<tr>
<td>Medium and large car segments, by attractiveness for FCEV vs. BEV</td>
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<tr>
<td>Off-road, utility and military vehicles</td>
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<td>Taxis, limousine services</td>
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<tr>
<td>Service fleets</td>
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<tr>
<td>SUVs</td>
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<tr>
<td>D segments for private use</td>
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<tr>
<td>A-C segment for private use</td>
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