On Electrons and Molecules

Lux Research's short vision on the future of energy and chemicals

Arij van Berkel, PhD Research Director Energy Transition

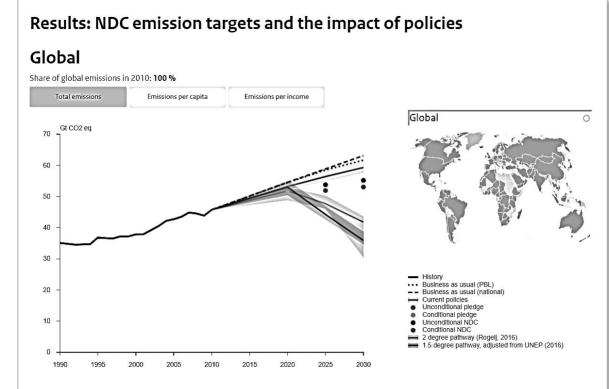


As NDC's of COP-21 materialize, the roadmap takes shape

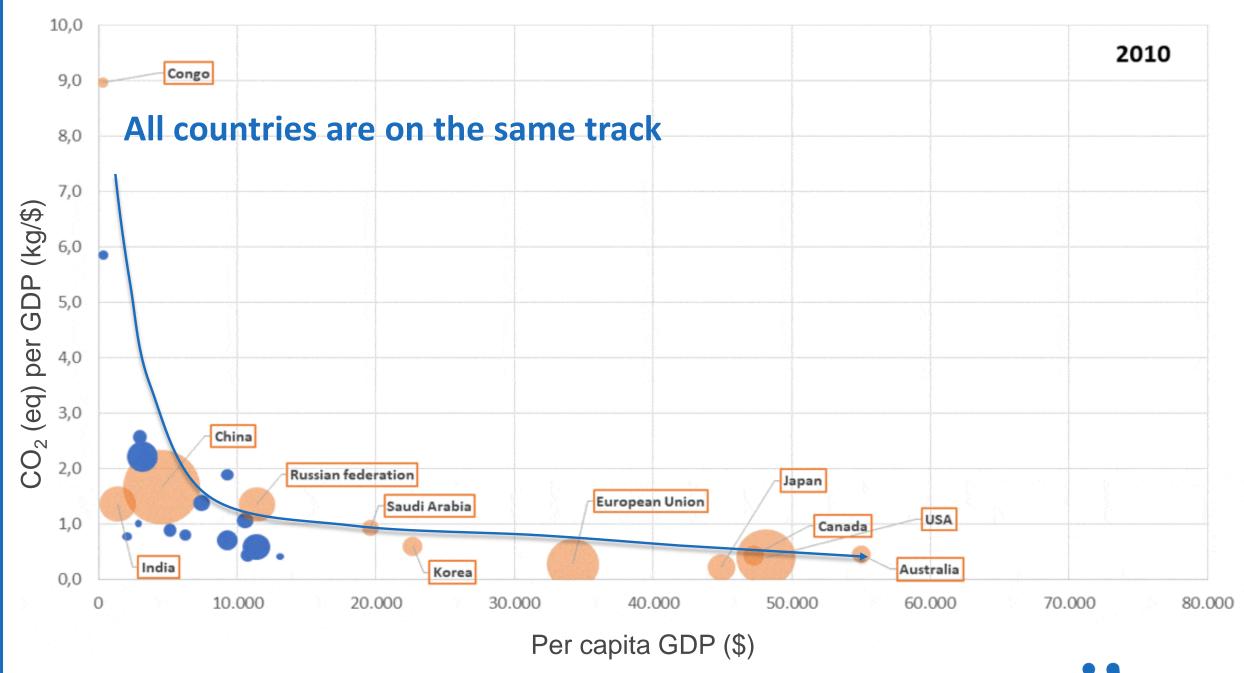
How COP-21 works

- Countries need to submit plans
- NDC: Nationally Defined Contribution
- Most plans are in now, at least until 2030
- Acceleration will need to happen post 2030

Take a look yourself, these people keep track: <u>http://themasites.pbl.nl/climate-ndc-policies-tool/</u>

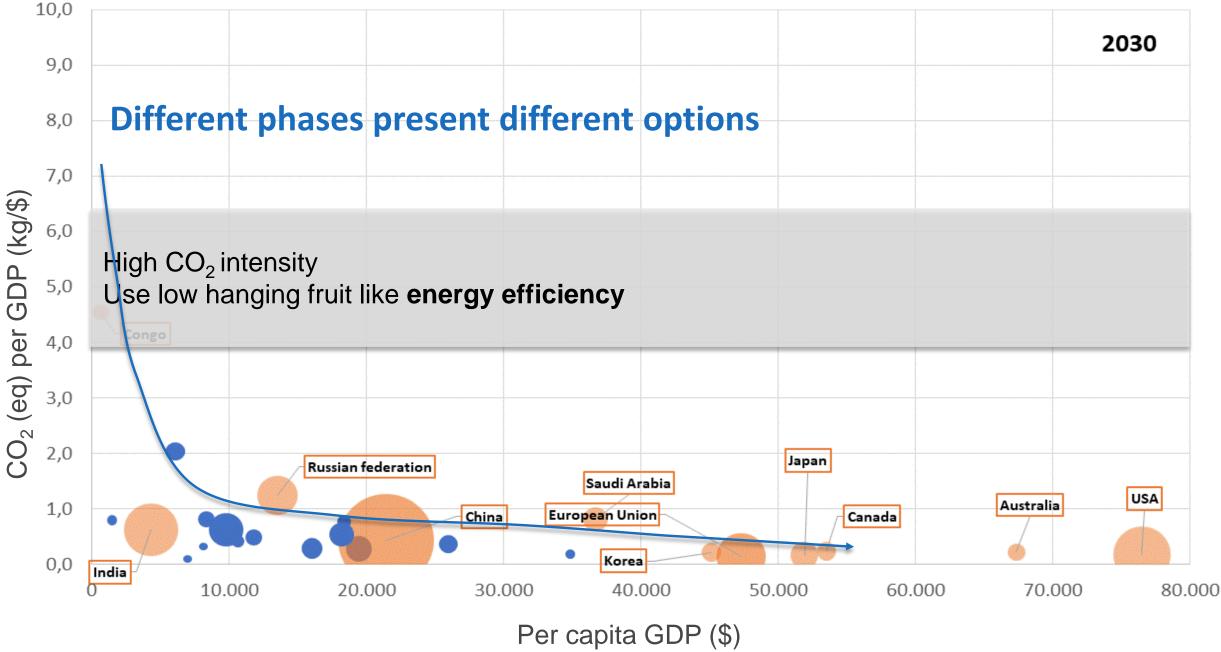






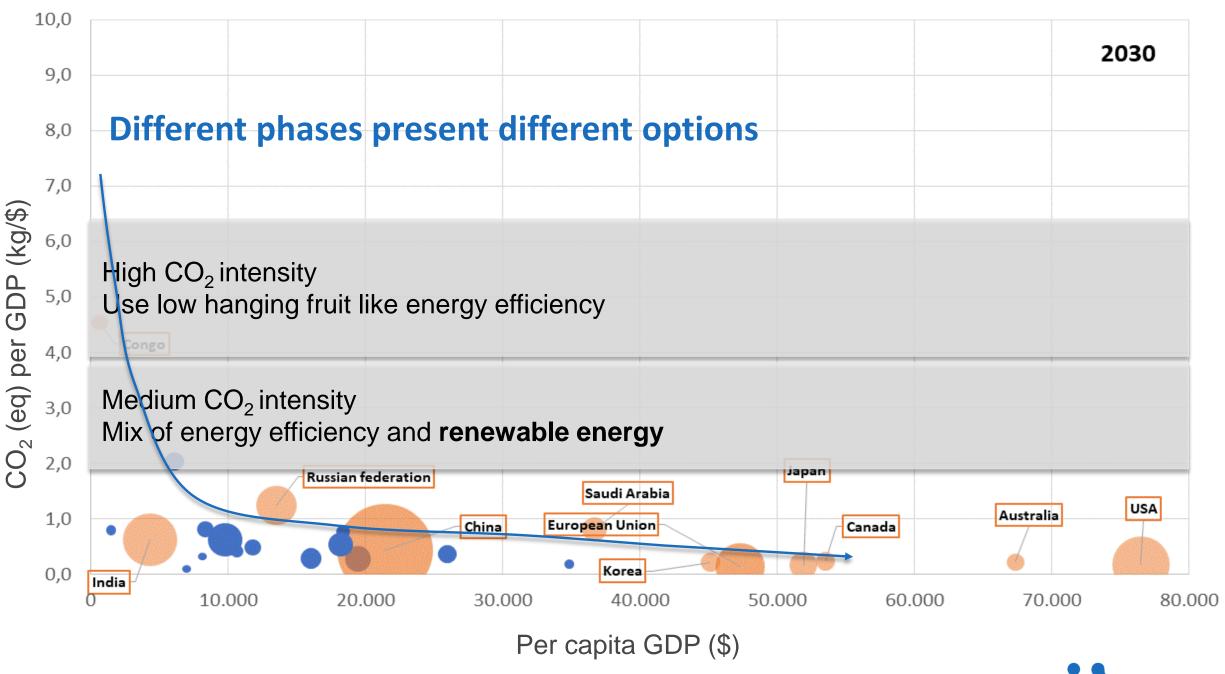
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³ Source: Lux Research 2018, based on UN and PBL data



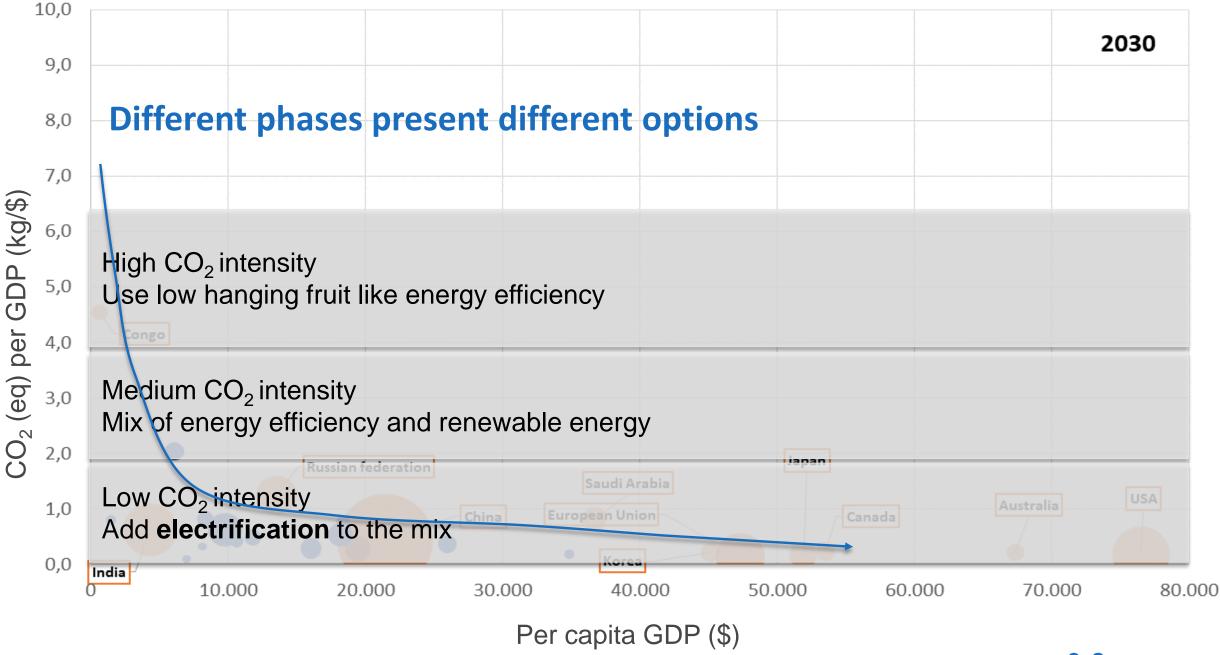
4 Source: Lux Research 2018, based on UN and PBL data





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5 Source: Lux Research 2018, based on UN and PBL data



6 Source: Lux Research 2018, based on UN and PBL data



The roadmap defines a multi-trillion dollar market

Global average required investment per year

2010 -- 2020 ■ 2020 -- 2030 7000 \$6.1T Billion USD per year 6000 5000 \$4.2T 4000 \$3.1T 3000 \$2.5T \$2.4T 2000 **\$0.8T \$0.9T** 1000 \$0.7T 0 Energy Renewable Electrification Total efficiency energy

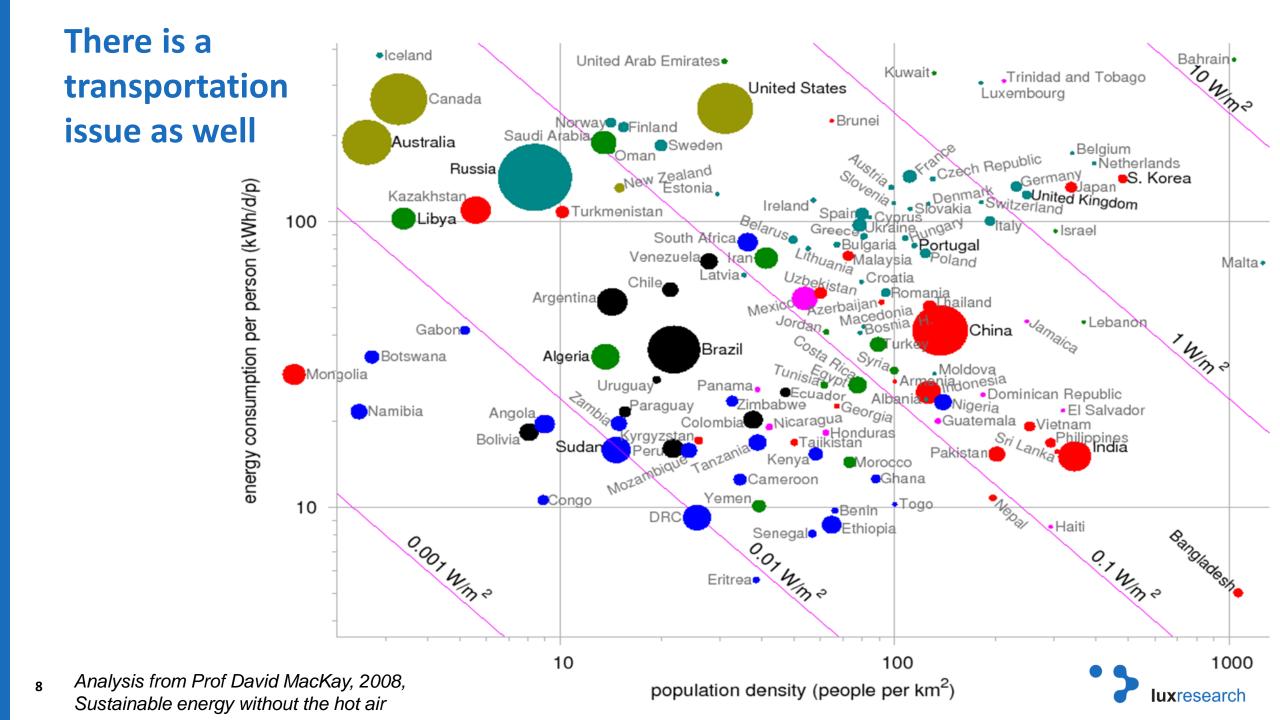
About 3% of global GDP

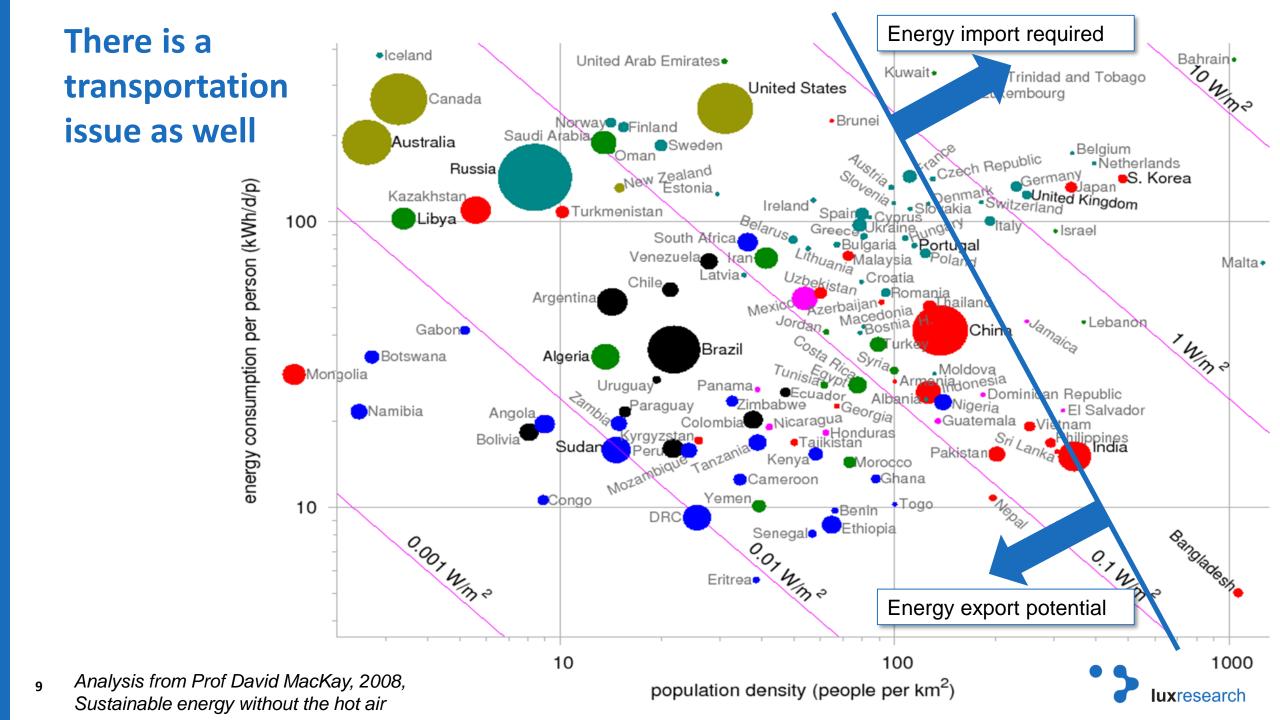
Varies by country; between 0.5% and 13% of GDP

Based on the most aggressive promised reduction

Still a conservative estimate; the most aggressive plans are not enough yet







The long-range energy transportation options







LNG:

• Clean

- Existing infrastructure
- High energy denstity
- Available today
- Still CO₂

Electrolyte:

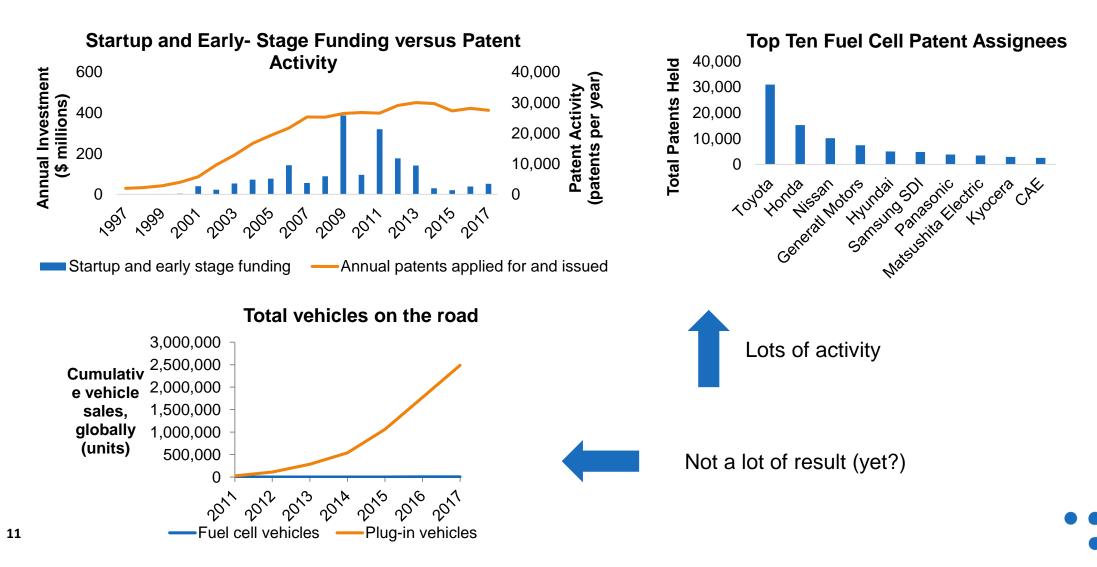
- Upcoming infrastructure
- New system
- Low energy density
- Electricity only

Hydrogen:

- Expensive infrastructure
- Versatile
- High energy density
- In development

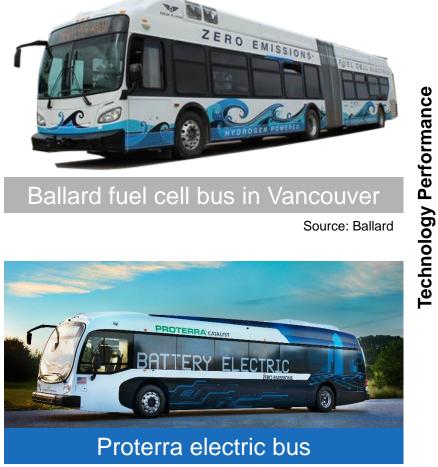


Hydrogen is the most versatile option, but difficult to deploy

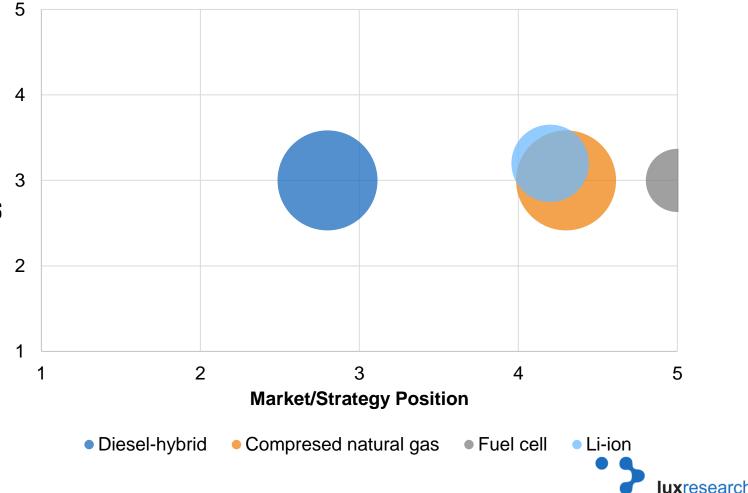


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Hydrogen is almost competitive for high-utilization vehicles



Intra-City Bus Powertrain Competitive Matrix



Source: Proterra

CO₂ utilization is the other driver for hydrogen





Only a coordinated approach will build a hydrogen economy

- Every application of hydrogen on its own merits is too expensive
- When there is a hydrogen commodity market and infrastructure, this picture changes
- All hydrogen applications must mature in the same timeframe
- Coordination (governments) is essential

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	Anthony Schiavo Accelerating Materials Innovation February 3, 2018	Very important [©]	passengers Li-lon batteri	f the approved train, Alstom's Coadia iLint, are set to operate in C by the end of the summer. Since compressed hydrogen has a gr ies, hydrogen fuel cells have a growing value proposition for train th some existing hydrogen infrastructure, such as Germany. Ciler	reater volumetric energy density than ns traveling relatively short routes in
Wery important April 16, 2018 April 16, 2018 Bable Statematic Proofs Statematic Shell and Anglo American invest in Hydrogen startup HyET Hydrogen, who is developing an electrochemical solution for hydrogen compression and purification. The interest shydrogen-based economy has long gamered interest in Asian countries such as Japan, with ol companies such addia Oil and JXTO Nippon already exhibiting a gradual push for hydrogen this year. However, clients should also take note of Anglo Americans invoit of a mining player investing in a Hydrogen start postioning fuel cells as a future market opportun mer C Mar Halik Entropy Storage Stores	SSAB is set to become the first major steelm primary steel production that releases no CC and will be a key demonstration of the potent effort closely, but be aware that this techniqu	Edit taker to build a hydrogen reduction steel plant – a technique for build a hydrogen reduction steel plant – a technique for build or Co, free steelmaking methods. Clients should monitor this te relies on many underdeveloped technologies and pieces of liable hydrogen – that mean it will take decades to transform Further reading from Lux Research: Vattenfall, SSAB	Childe Holzinger Sum 25,2018 Childenative Fuels South Korea to invest \$2.3 billion cosystem by 2023 Norough public-private partnerships, South Korea is look 16,000 fuel cell electric vehicles by 2023. The funds will cell stacks, refueling stations, and hydrogen through CN in fuel cells in the past, the country has not enjoyed as m about 51.2 billion in its Hydrogen vision since 2014 and b Olympic bid. Clients should still consider Japan to be lead South Korea and Germany as strong players in the fuel	Very important	act to provide 14 hydrogen fuel cell .coomotive Works is currently x Research: Alstom, Indian Railways
Partnership A power-to-gas project from Sunpower an breathe life into hydrogen's deflating prosp		Runeel Daliah Atternative Fuels Tores November 8, 2017 Audi renews commitment to CO2-	Very important	ther reading from Lux Research: South Korea Ministry of Trade, Industry and Energy (MOTIE)	
Nouryon, Tata Steel, and Port of Amsterdam collaborate on feasibility study of 100 MW hydrogen production facility	ortant 🕤	e-diesel facility Last week, Audi announced plans for a second CO2-to-dik Holding due for 2019 in Switzerland. The 105,000 gallons reverse water gas shift and Fischer Tropsch (RWGS/FT) p hydrogen. Audi's first project in the space. a 15,000 GPV	per year (GPY) diesel facility will use a combined process to produce diesel from CO2 and renewable		
This announcement is notable for multiple reasons: It is the biggest proposed PEM electrolysis facility, and it is Nouryon's (formerly AkzoNobel Specialty Chemical) first major announcement since its rebranding. This announcement is a step in the right direction, as it seeks to tackle the cost of electrolysis by scaling up the process and involves major stakeholders in the steel and chemical industries. Clients should recognize that wit this is only a feasibility study and commercialization remains distant, it represents an important step toward lan scale, low-cost production of hydrogen.	lie	nyunger. Auf sins project in the space, a 10,000 GFT i only produced 85 gailons of diseal as of May 2017. While expensive for commercialization; based on our estimates a using RWGS/FT exceeds \$22/gallon. For the original news article, click here ♂.	groundbreaking, CO2-to-diesel remains far too		
For the original news article, click here G. Partnership Further reading from Lux Research: Tata Steel, Nour	yon	Project Further	r reading from Lux Research: Audi, Climeworks, Sunfire, INERATEC	J	luxresea

ergy Storage More..

Germany approves the world's first train powered by hydrogen

Very important 6

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Arij van Berkel, PhD

Research Director Energy Transition arij.vanberkel@luxresearchinc.com +31 6 512 97 513 +31 20 280 7908