Start Now – RNG is How

Agenda

- Introduction – Dan Gage, President of NGVAmerica
- Presentation by Hexagon – Eric Bippus and Ashley Remillard
- Discussion led by Dan Gage
- Audience participation and discussion
- Wrap up – Dan Gage

Start Now – RNG is How

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https://ngvamerica.org/resource-center/

RNG: a viable decarbonization strategy for medium- and heavy-duty trucks

Eric Bippus, SVP Global Sales and Marketing
Ashley Remillard, VP Legal

March 2, 2022

HEXAGON

Our vision

CLEAN AIR EVERYWHERE

Our purpose

DRIVING ENERGY TRANSFORMATION

Our values

INTEGRITY & DRIVE

Two Hexagon Group companies providing clean energy solutions for transport sector

HEXAGON AGILITY

G-Mobility LOW EMISSION

- COMPRESSED NATURAL GAS
- LPG
- BIOGAS / RENEWABLE NATURAL GAS

HEXAGON PURUS

E-Mobility ZERO EMISSION

- BATTERY ELECTRIC
- HYDROGEN

Hexagon Agility and Purus have over 70,000 commercial vehicles on the road using one of our clean energy solutions

Global capabilities

Hexagon administration, marketing/sales and representative offices

1. Ålesund, Norway
2. Oslo, Norway
3. Costa Mesa (CA), U.S.
4. Heath (OH), U.S.
5. Chateauroux, France
6. London, United Kingdom
7. Wroclaw, Poland
8. Klagenfurt, Austria
9. Nizhny Novgorod, Russia
10. Santiago, Chile
11. Cali, Colombia
12. Bangalore, India
13. Singapore
14. Beijing, China

Hexagon production sites and engineering hubs

15. Raufoss, Norway
16. Kassel, Germany
17. Munich, Germany
18. Weeze, Germany
19. Kelowna (BC), Canada
20. Lincoln (NE), U.S.
21. Taneytown (MD), U.S.
22. Denver (CO), U.S
23. Fontana (CA), U.S.
24. Ontario (CA), U.S.
25. Salisbury (NC), U.S.
26. Wixom (MI), U.S.

Headquarters
1. Ålesund, Norway
2. Oslo, Norway

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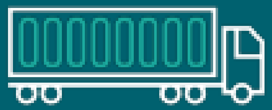
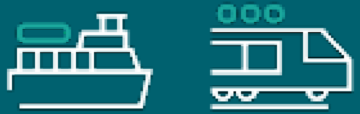
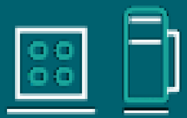
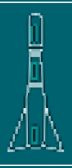
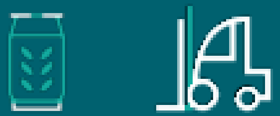
Market segments – Energy agnostic

MARKET SEGMENTS	FUEL & ENERGY SOURCES
Automotive & HD Transport Fuel cylinders and systems for light-duty, medium-duty and heavy-duty vehicles; battery packs for MD/HD trucks 	Hydrogen | Biogas / RNG | CNG | LPG | EV
Mobile Pipeline Storage and transportation cylinders and modules for off-pipeline applications 	Hydrogen | Biogas / RNG | CNG
Maritime & Rail Fuel and storage cylinders for marine and rail 	Hydrogen | Biogas / RNG | CNG
Ground storage Cylinders for ground storage  **Aerospace** Cylinders for spacecrafts, satellites, airplanes, drones 	Hydrogen
Household and leisure LPG cylinders for leisure activities, household and industrial applications 	LPG (Propane and Butane)

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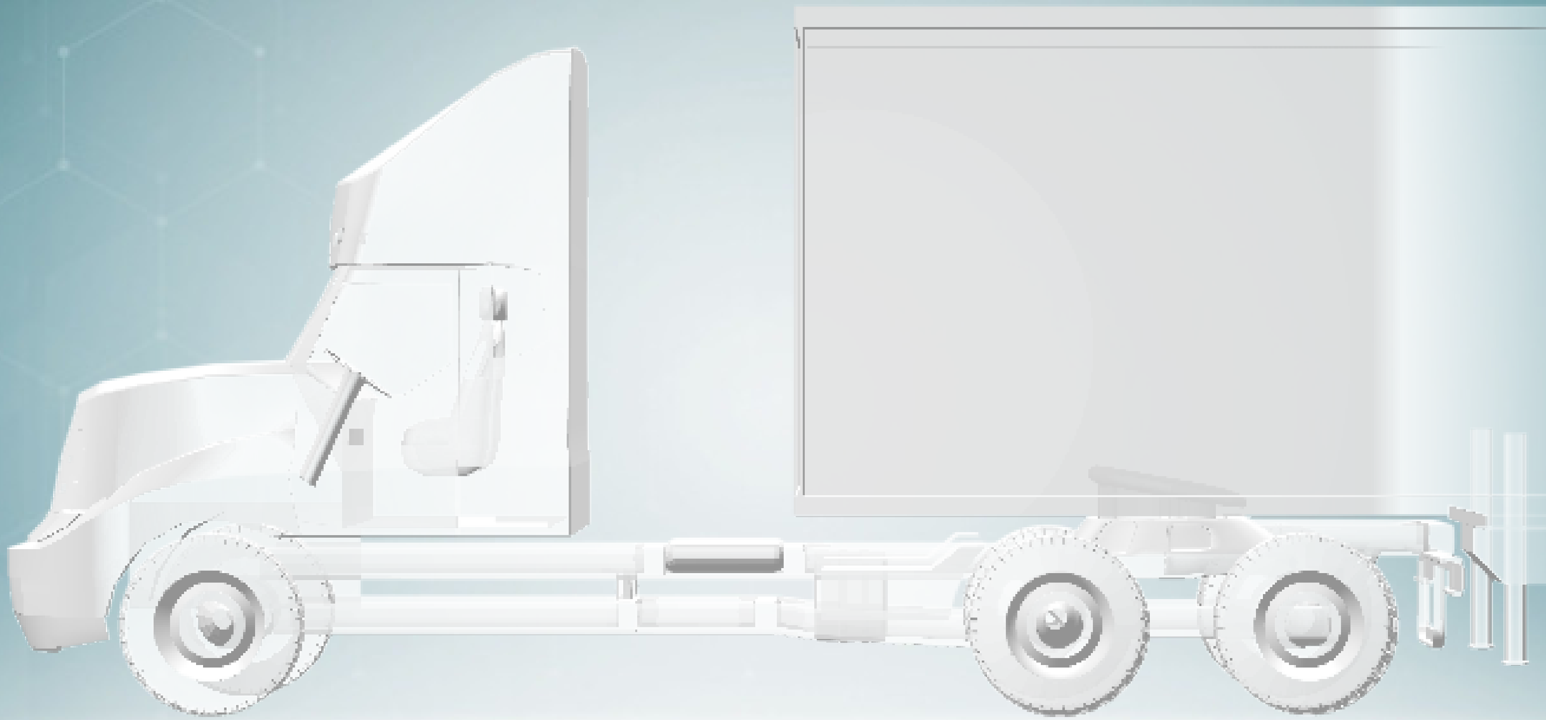

Class 7 & 8 Day Cab

Typical annual mileage 60,000 – 100,000 miles

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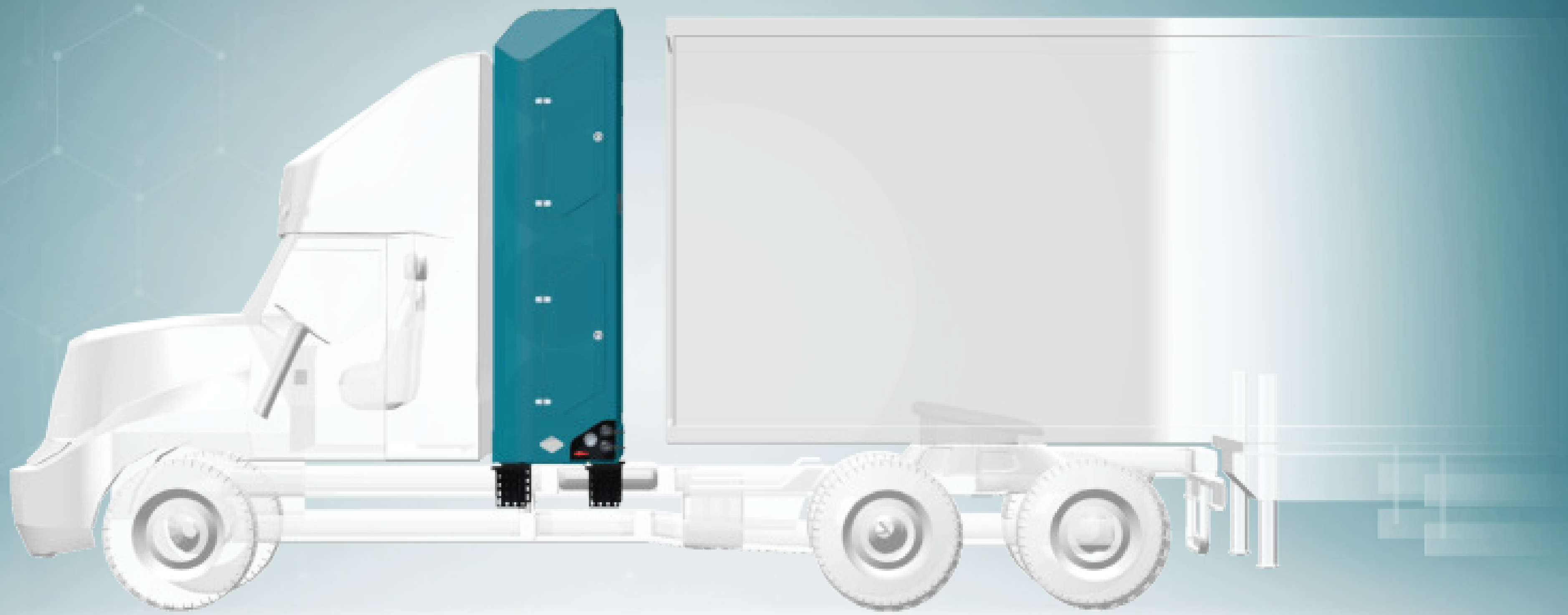

Class 7 & 8 Day Cab

Typical annual mileage 60,000 – 100,000 miles
Hexagon Agility ProCab® 175 Fuel System

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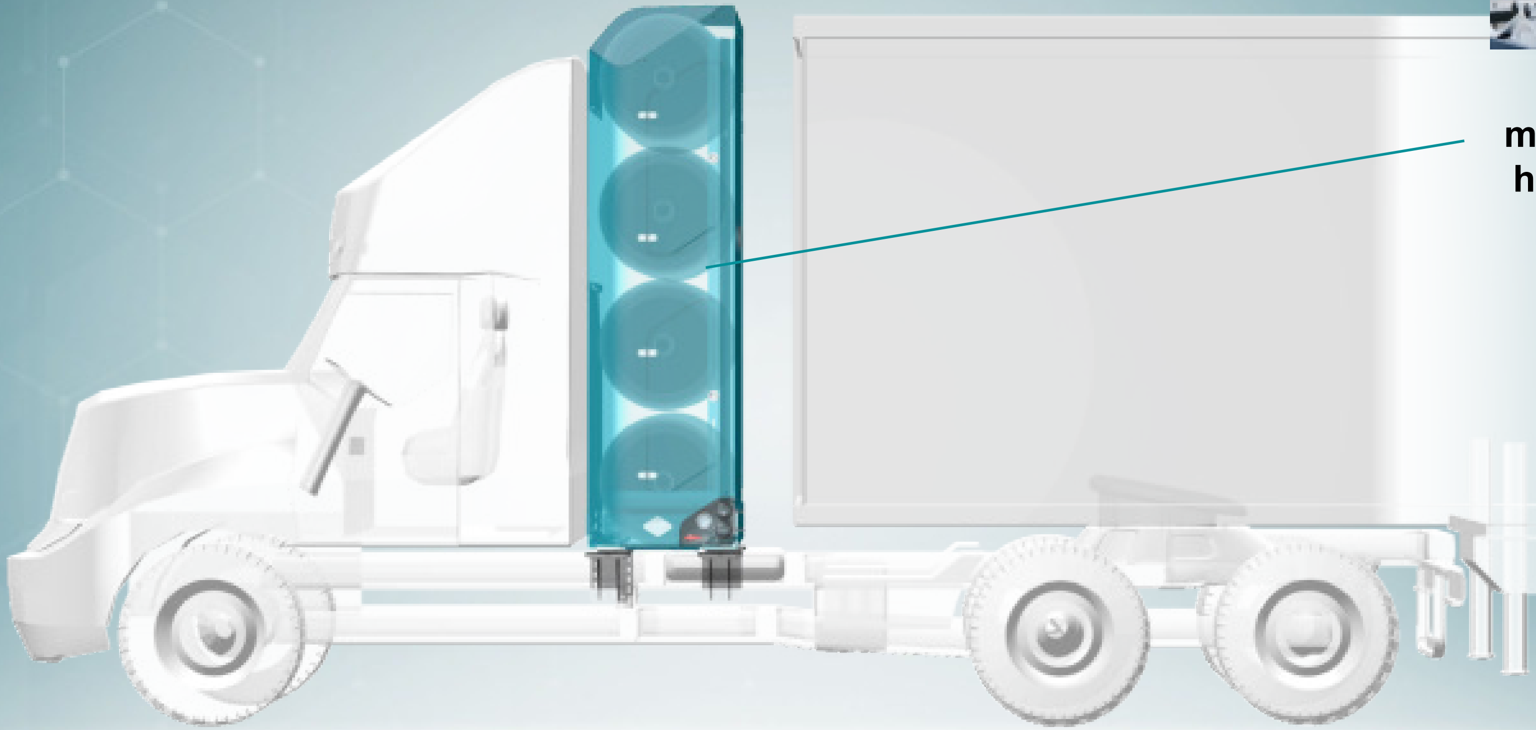
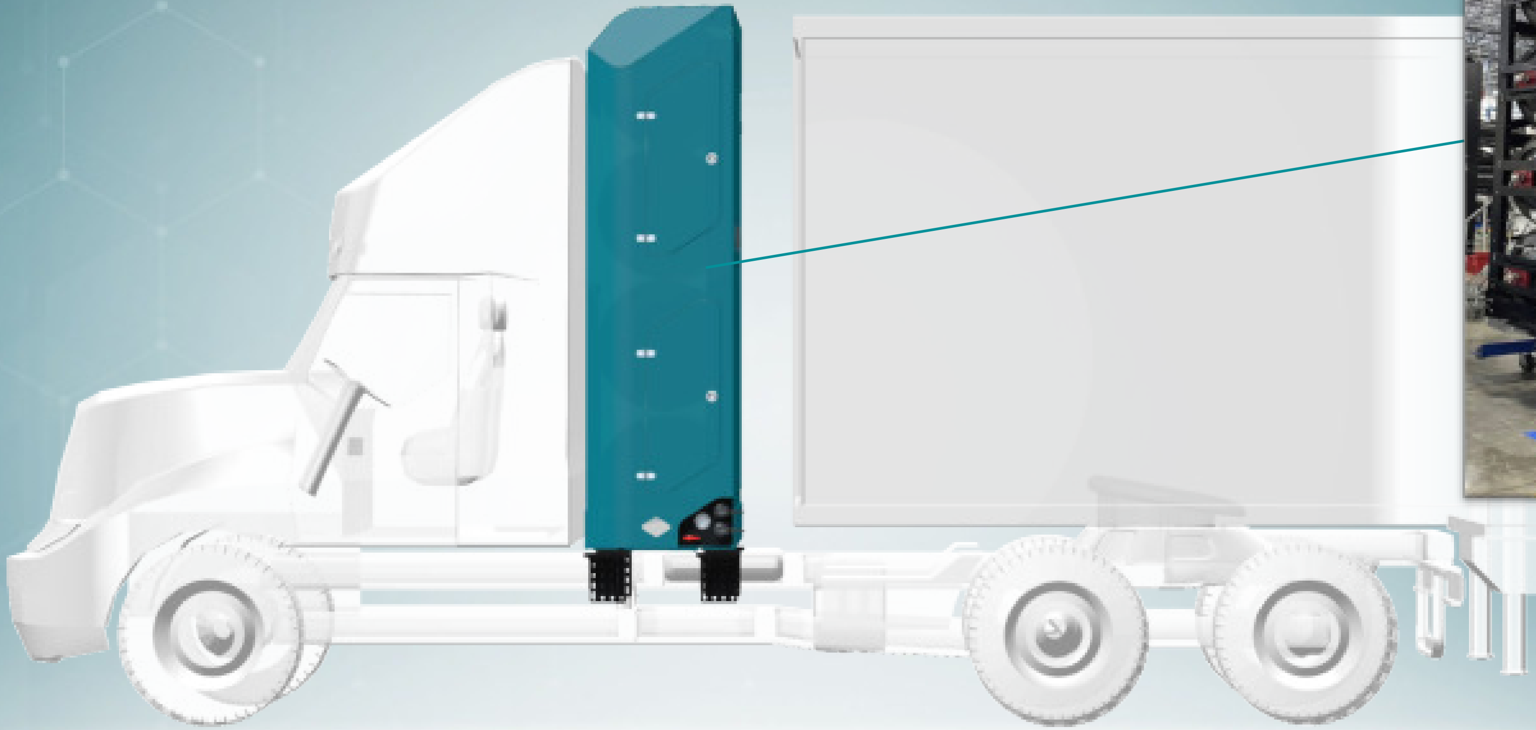


Worlds largest manufacturer of Type 4 high pressure vessels

USA - Germany

Class 7 & 8 Day Cab

Typical annual mileage 60,000 – 100,000 miles
Hexagon Agility ProCab® 175 fuel system
Up to 850 mile range



Fully integrated assembly and metal fabrication of fuel systems

CNG - USA – Germany – Norway
H2 – Hexagon Purus Canada

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TruckWings™ active cab-trailer-aerodynamic system coupled with our CNG (RNG) ProCab® unit achieves 4-6 % fuel savings

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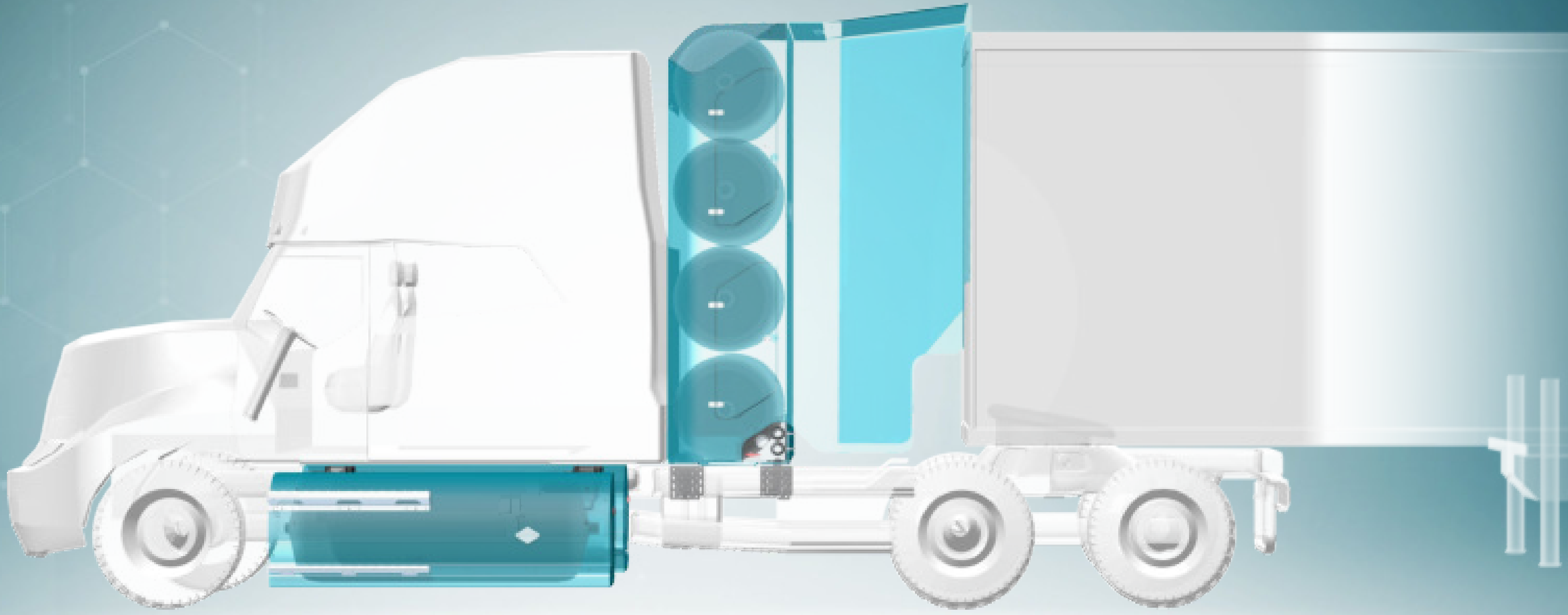

Class 8 Sleeper – 200,000 to 250,000 trucks sold per year

Typical annual mileage 100,000 – 200,000+ miles

Hexagon Agility ProCab® 175 with dual ProRail® 45 (265 DGE)

1,200+ mile range

Hexagon group supporting the fleets journey to a clean future

Class 8 RNG Day Cab

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Class 8 Hydrogen Truck

UPS
FedEx
amazon
FritoLay

Class 8 1,200+ mile range Sleeper

HEXAGON PURUS

MD and HD BEV

RNG Yard Truck

RNG Package Car

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Decarbonizing the transportation sector with urgency is required to reach global climate targets in 2025 and 2030

Transportation is responsible for almost 20% of global CO_2 emissions

On average there are +350,000 HD transport vehicles sold in the North America

Over 97% are still diesel

Government sustainability targets for transport are being fast-tracked to 30% reduction by 2030

Source: Third Party Source

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RNG market opportunity

How RNG is decarbonizing the transportation sector

What will we accomplish today regarding RNG's suitability as a key energy source for HD transport

Sufficient GHG reduction?	How does RNG compare to other clean energy alternatives for HD transport Can RNG make a substantial impact by 2030 in reducing GHG emissions
Supply potential?	Is there sufficient supply of biomass to potentially support HD transport energy needs Is infrastructure and distribution in place to support immediate mass adoption
Technology in place?	Do OEMs and Tier 1 suppliers offer sufficient platforms for todays HD transport fleet In what types of fleet use patterns does RNG make the most sense
Supportive Regulation?	What is happening globally in regard to supportive legislation for RNG Are there incentives in place to assist in the adoption of RNG
Does TCO support adoption today?	In order for any solution to be adopted can today's fleet operate RNG profitably vs diesel and other clean energy solutions in mass

What will we accomplish today

Sufficient GHG reduction?

How does RNG compare to other clean energy alternatives for HD transport

Can RNG make a substantial impact by 2030 in reducing GHG emissions

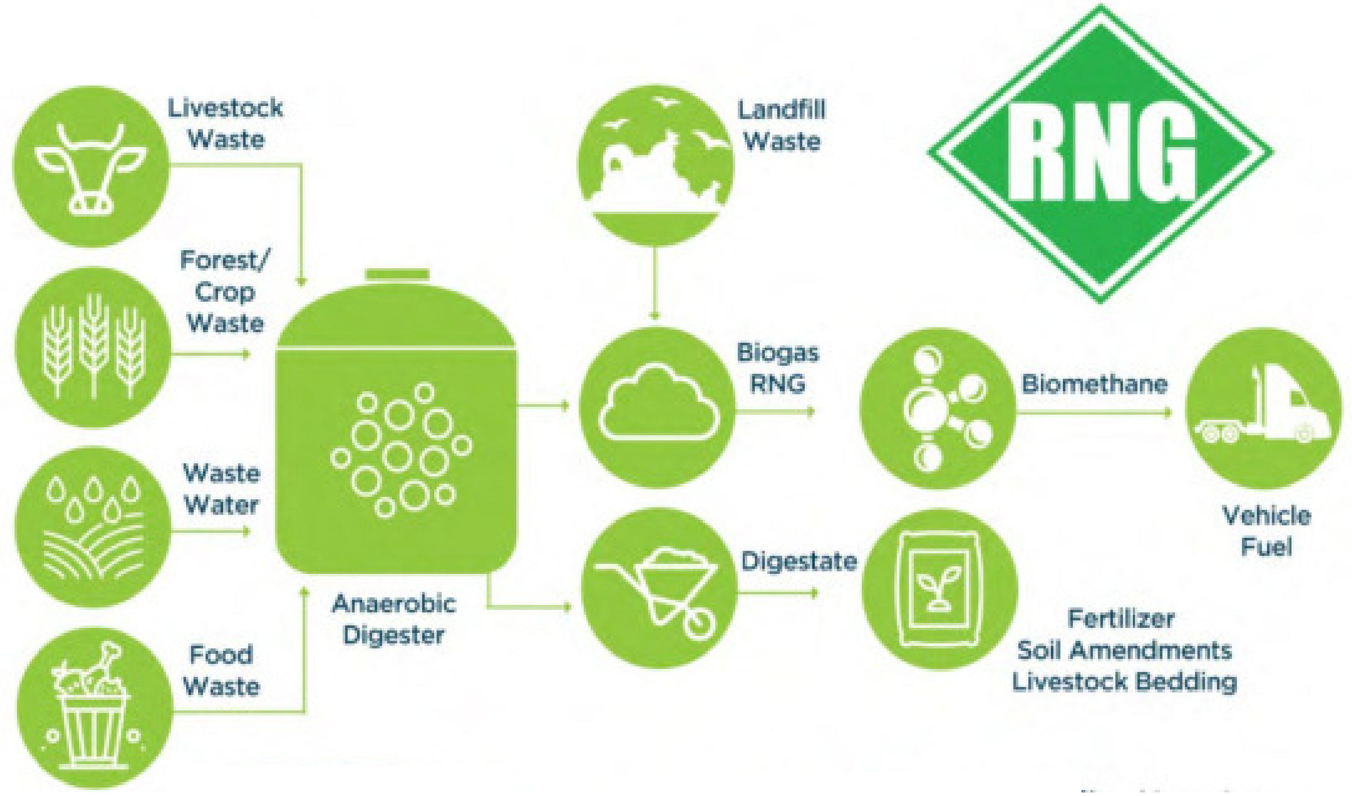
Supply potential?

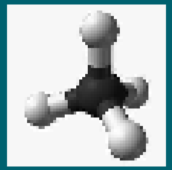
Technology in place?

Supportive Regulation?

Does TCO support adoption today?

How is waste converted to RNG?





Production of RNG involves the capture of methane from escaping into atmosphere

RNG and geologic natural gas can be blended at any mix ratio without impact in performance but with reduction in pure RNG CI score

Natural gas transport vehicles can run RNG, geologic natural gas or blended gas without modification

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RNG has significant well-to-wheel CO_{2-eq} emission savings compared to fossils

— CO_{2-eq} emission benchmark of diesel from fossils

Powertrain	Energy demand[1]		Energy carrier	Well-to-wheel CO_{2-eq} emissions in g/km[7]
ICE-Methane (e.g. CNG)	17[2] kg/100km	216 kWh/100km	Geologic	543
			RNG by manure	-745
			RNG excl. manure	147
ICE-Diesel	20 l/100km	196 kWh/100km	Fossil	663
BEV		90 kWh/100km	EU grid 2019	246
			Brown coal electricity	1,069
			Wind/solar electricity	3
FCEV	4.2 kg/100km	140 kWh/100km	H_2 from natural gas	504
			Green hydrogen	10

1. Reference vehicle 18 t rigid truck, Mercedes-Benz Actros, 7.7 liter displacement, 200 kW, 1,100 NM, average payload 65% – diesel fuel consumption averaged based on webfleet, BEV and FCEV energy demand synthesized from various publications considering driving cycle, efficiency improvement and payload correction; 2. Considering a stoichiometric spark-ignition otto-cycle, energy demand ~10% higher than ICE-Diesel based on ICCT "Decarbonization of on-road freight transport and the role of LNG from a German perspective", 2020, p. 28, corrected for long-haul cycle; 3. Synthetic natural gas; 4. JEC Well-to-Wheels Report v5, 2020 – synthetics based on pathways with electricity and CO_2 from renewables; 5. RED II, Annex VI, published 21.12.2018; 6. Source: EEA GHG inventory 2020; 7. Methodology: multiplication of energy demand with specific well-to-wheel CO_{2-eq} emissions in g/MJ

Depending on biomass source **RNG has an 80-200% reduction in CO_{2-eq} emissions** on a well-to-wheel basis

RNG usage **reduces global warming by capturing methane** otherwise emitted to the atmosphere

BEV and FCEV only achieve GHG emission savings compared to ICE-Diesel, if they use energy from renewable sources

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What will we accomplish today

Sufficient GHG reduction

✓

Supply potential?

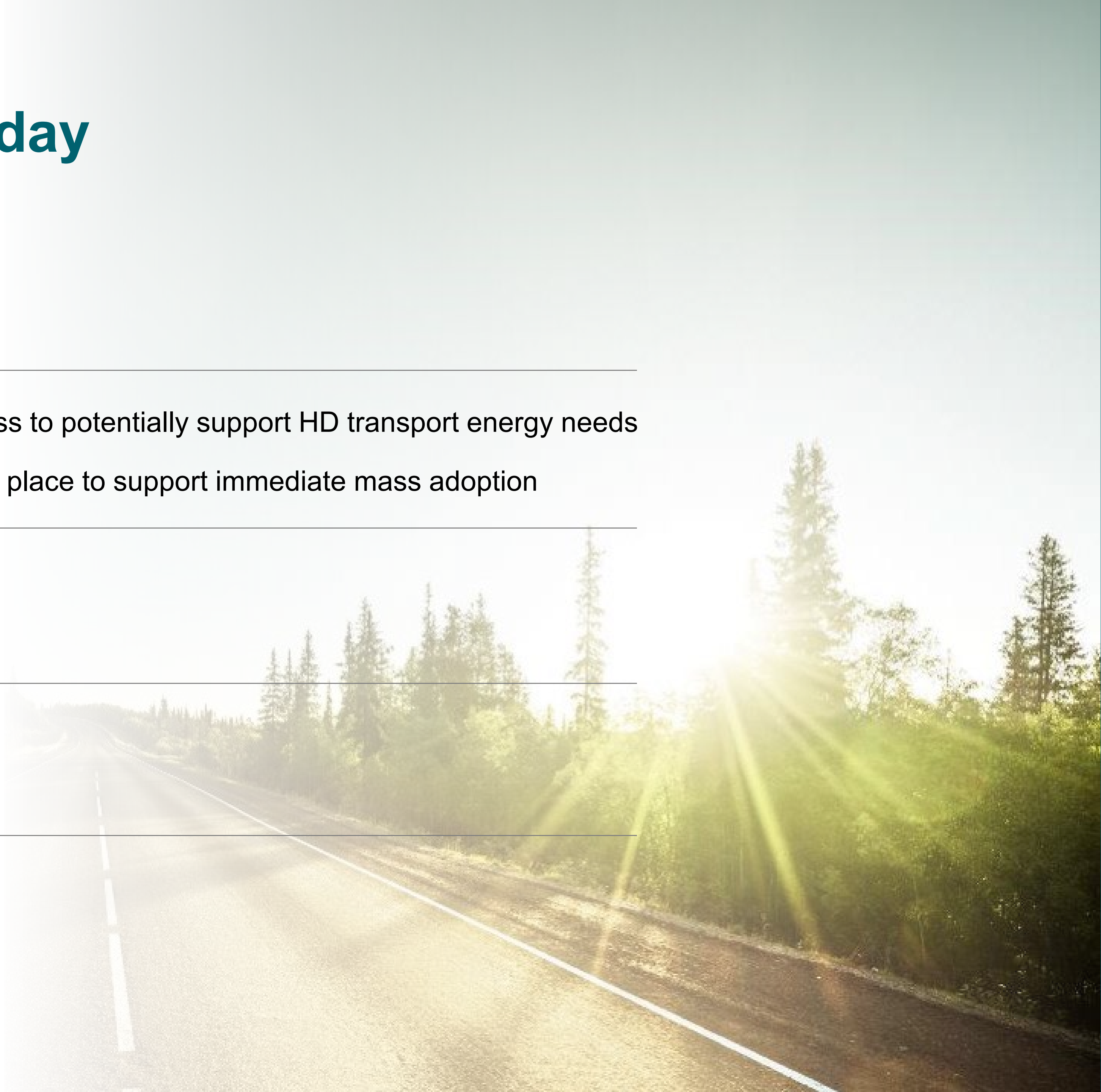
Is there sufficient supply of biomass to potentially support HD transport energy needs

Is infrastructure and distribution in place to support immediate mass adoption

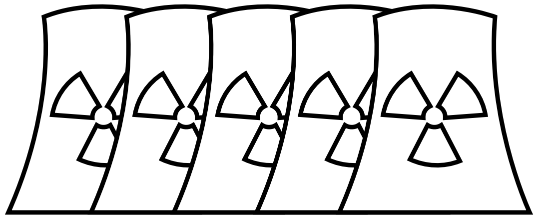
Technology in place?

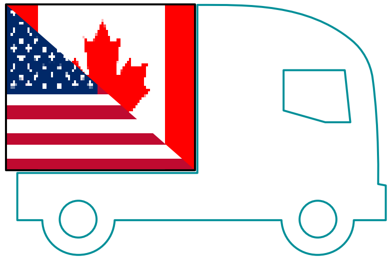
Supportive Regulation?

Does TCO support adoption today?



We frequently use the energy unit EJ in this report, short for Exajoule or 1018 Joule





1 EJ = Energy output of the 5 largest nuclear power plants operated at full capacity for one year or ~10% of Europe's nuclear energy supply = 5x EJ would meet the demand of HD on road transport in North America

Conversion to other energy units

1 EJ = 24 MtOe (million tons of oil equivalent) = 278 TWh (Tera watt-hours) = 947,817,000 MMBtu (million British thermal units)

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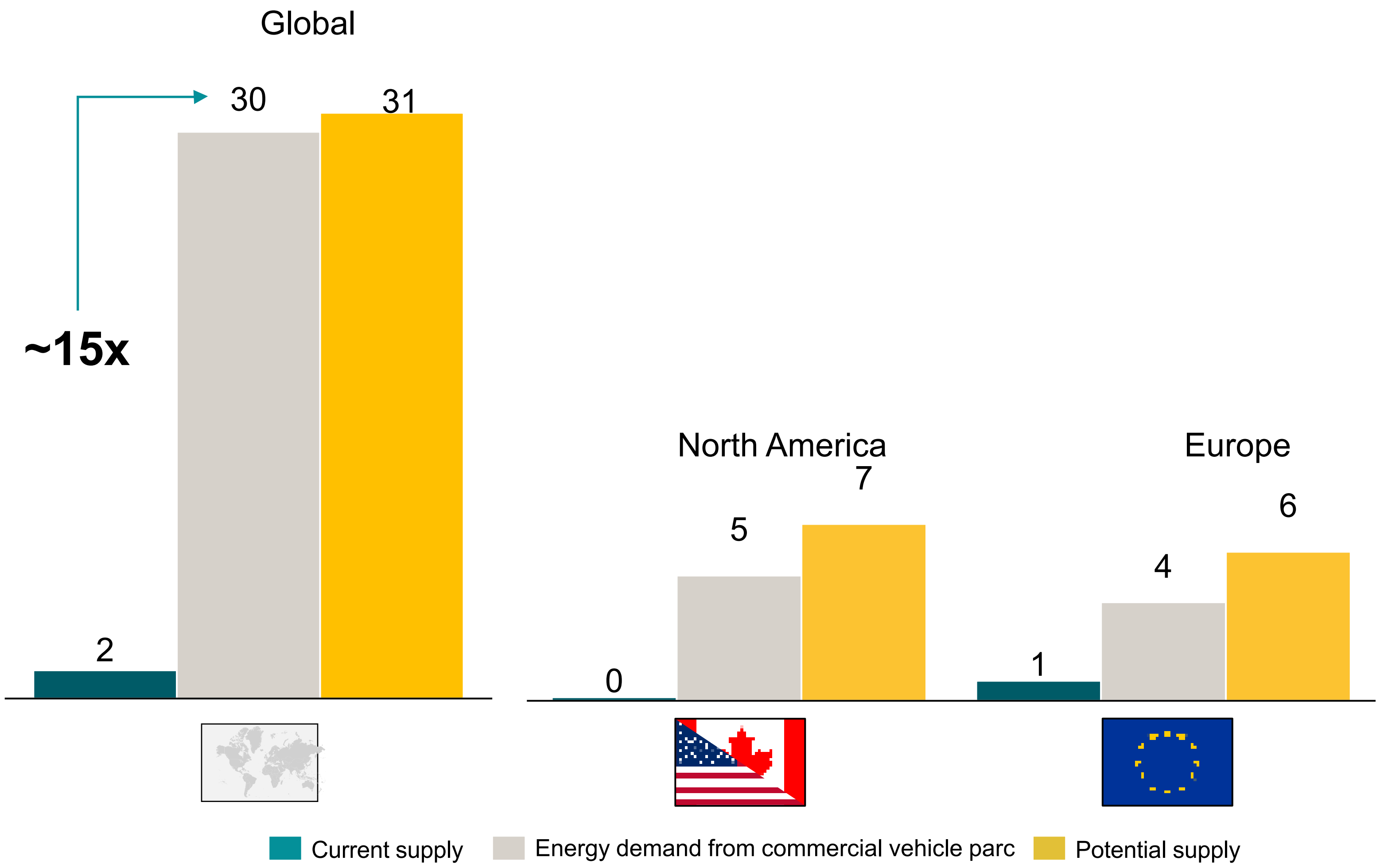
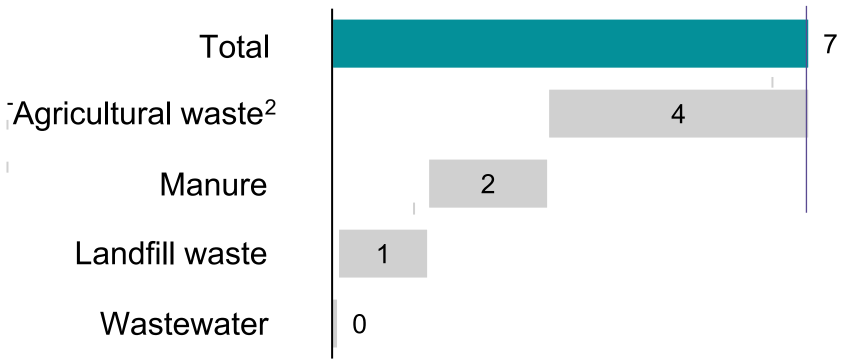
No potential supply constraints of RNG for commercial vehicles, however currently only small percent of potential biomass tapped for RNG production



Source: Third Party and IEA Outlook for RNG and biogas 2020

North America can increase its biomass conversion to RNG production by ~70x

	Biomass supply for RNG production by raw material[1], EJ	Potential of biomass supply for RNG production by raw material[1], EJ	Could there be sufficient RNG for commercial road transport?	Evidence	Sources
North America			Significant supply upside of RNG available	**Global 15 X** theoretical RNG potential supply available vs. production today RNG could supply up to **23% of today's natural gas** energy	iea
			No supply constraints of RNG for commercial vehicles	In EU and NA **the theoretical supply potential for RNG is 1.5 X** of commercial road transport energy demand	IRENA, ergar

Currently less than 1EJ in production in North America

1. Considers all biomass for either bio gas or bio methane production, 2018 figures., 2. Includes crop residues and woody biomass, 3. Assuming same average growth rate

Source: IEA Outlook for biomethane and biogas 2020

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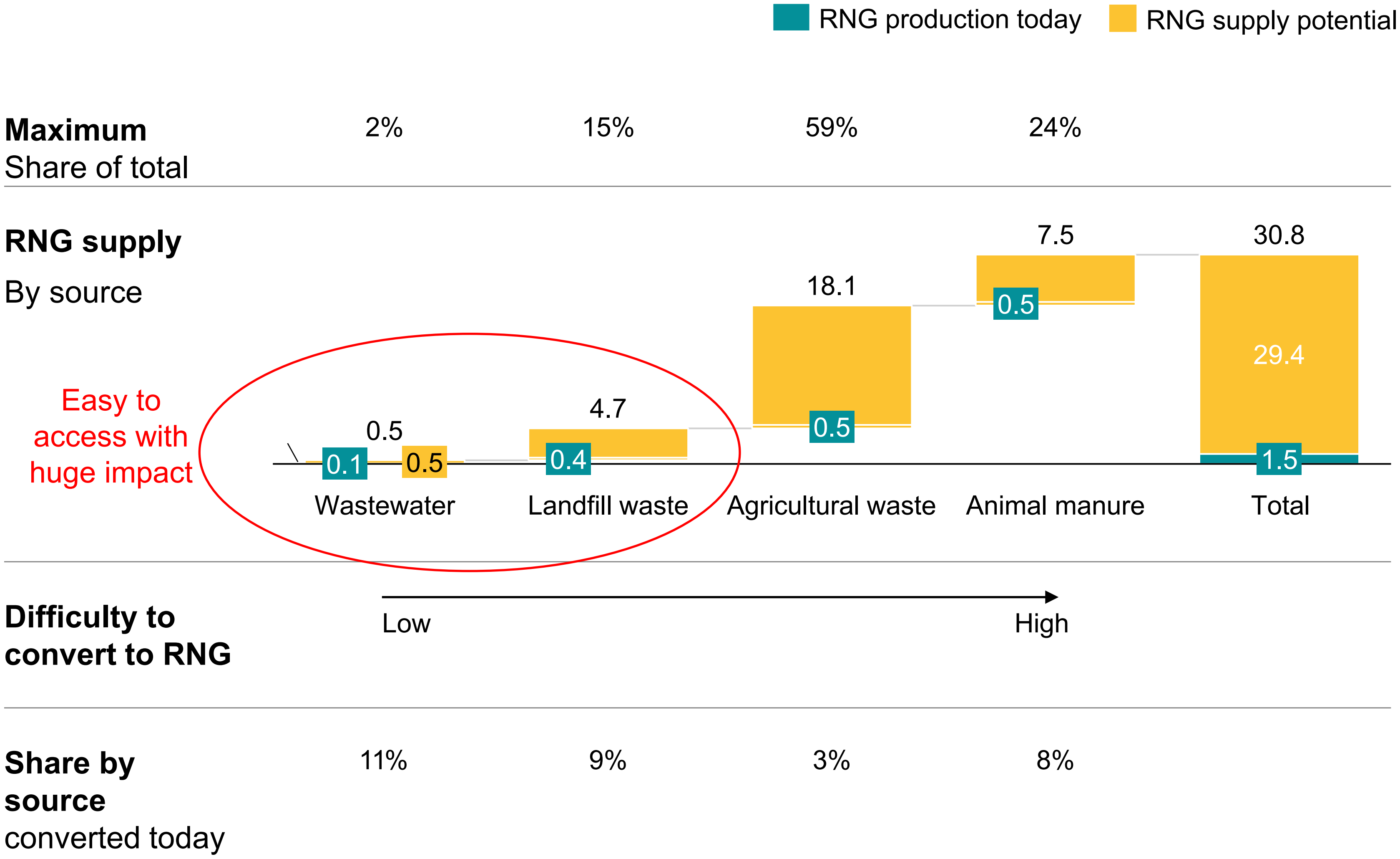
There are varying degrees of complexity in converting biomass to RNG



Key takeaways

Wastewater and landfill waste raw materials easiest to access and already today ~10% converted

By accessing full wastewater and landfill waste 17% of RNG supply can be produced relatively easy

Agricultural waste and animal manure due high localization is more difficult to scale

Source: Third Party Source

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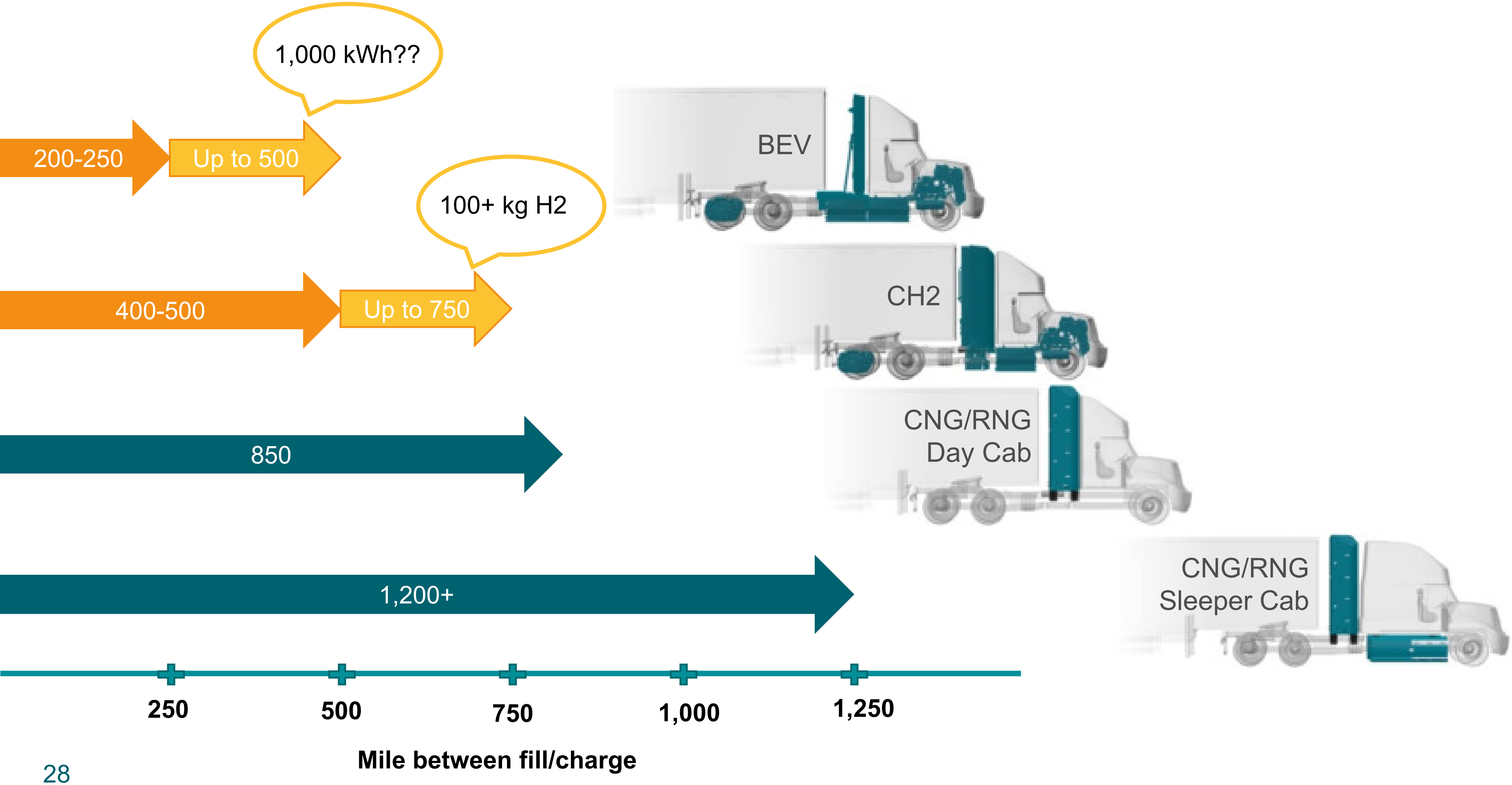
What will we accomplish today

Sufficient GHG reduction	✓
Supply potential	✓
Technology in place?	Do OEMs and Tier 1 suppliers offer sufficient platforms for todays HD transport fleet In what types of fleet use patterns does RNG make the most sense
Supportive Regulation ?	
Does TCO support adoption today?	

BEV and H2 have demonstrated suitability for HD regional haul applications but require much improvement to solve HD long-haul class 8 routes



The study concluded there will be multiple clean energy solutions required to meet the 2030 emission reduction targets

X% Use case split by segment | Niche market position for ICE-RNG | Key market position for ICE-RNG

Powertrain choice in 2030	City-haul	Regional-haul	Long-haul
LCV	BEV 65%	BEV Diesel 30%	BEV Diesel 5%
MDT	BEV 35%	BEV CNG/RNG Diesel 60%	FCEV CNG/RNG LNG/LGB (EU) Diesel 5%
HDT	BEV 10%	BEV CNG/RNG Diesel 20%	FCEV CNG/RNG LNG/LGB (EU) Diesel 70%

200-250K HD Trucks p/yr

Source: Third Party Source

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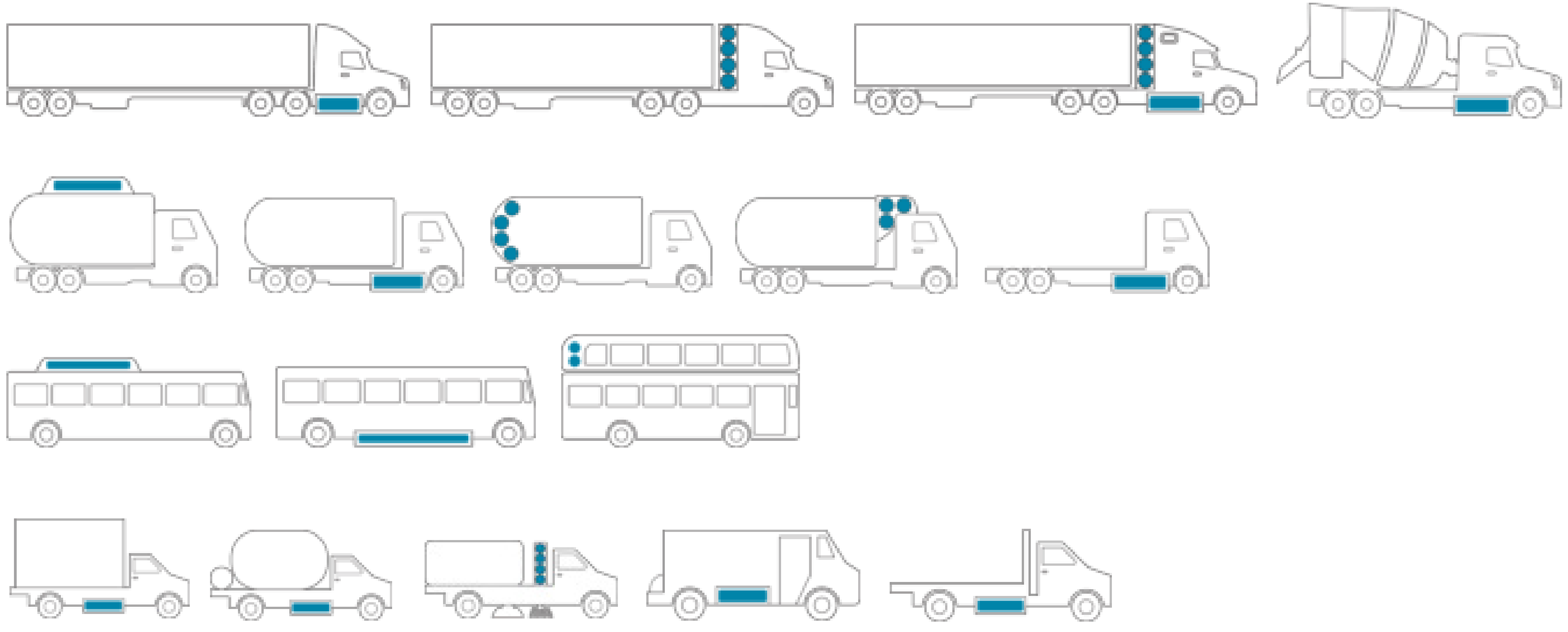
RNG is a mature technology with over 100 available factory installed solutions globally

Heavy Duty Truck

Refuse

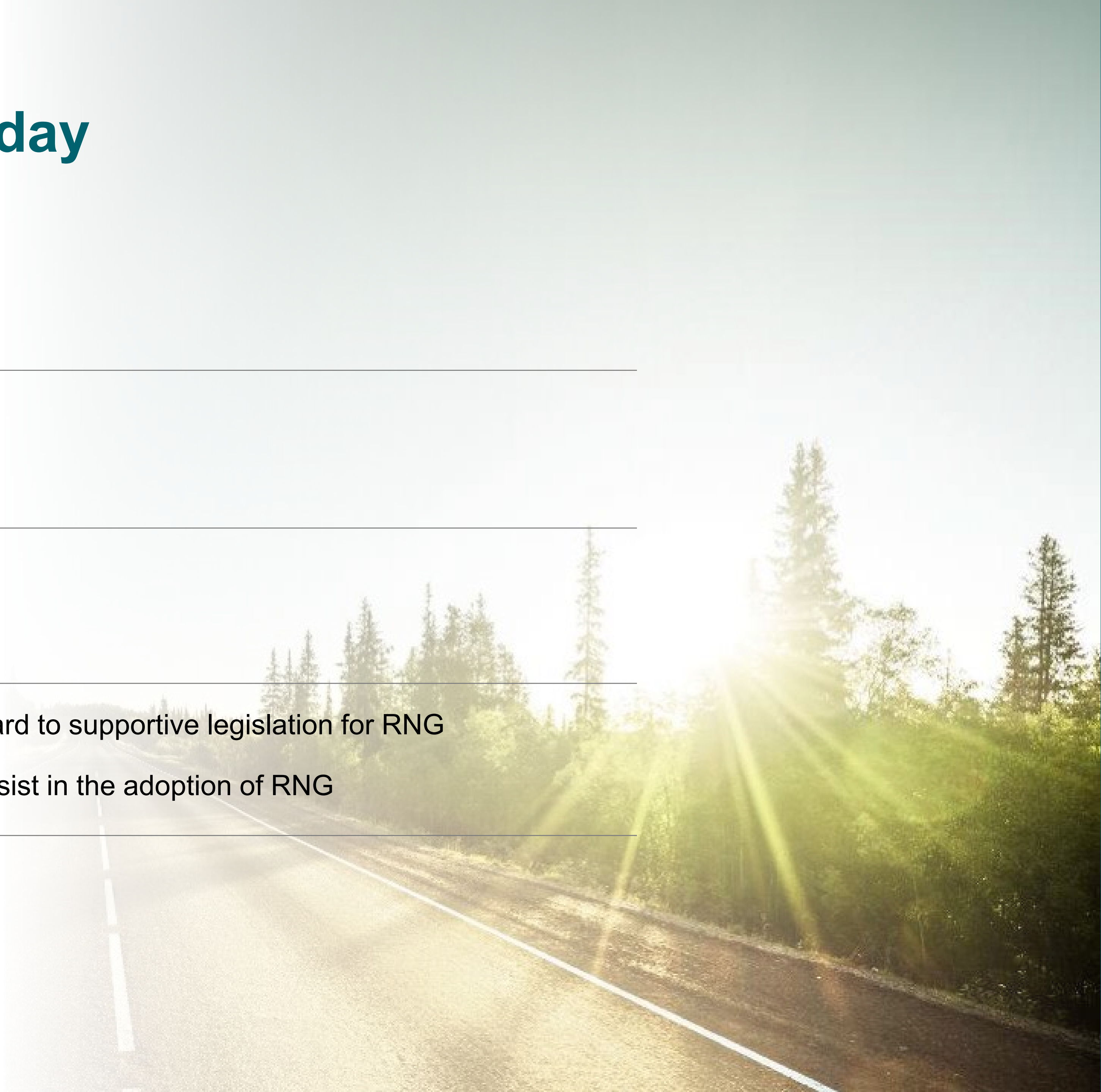
Bus & Coach

Medium Duty



Notable OEMs

What will we accomplish today



Sufficient GHG reduction

Supply potential

Technology in place

Supportive Regulation?

What is happening globally in regard to supportive legislation for RNG

Are there incentives in place to assist in the adoption of RNG

Does TCO support adoption today?

RNG Regulatory Landscape

RNG is essential to achieving global emission goals

Ashley Remillard

HEXAGON

COP26

Held in Glasgow, Scotland from October 31 to November 12, 2021

Global Methane Pledge: over 111 countries promised to cut methane emissions by at least 30% by 2030

Biden unveiled U.S. Methane Emissions Reduction Action Plan to reduce methane emissions by 30% below 2020 levels by 2030

UN CLIMATE CHANGE CONFERENCE UK 2021

IN PARTNERSHIP WITH ITALY

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EU Regulatory Landscape

European Green Deal:

No net emissions of greenhouse gases by 2050; adopted December 2019

European Climate Law:

Legally binding target of net zero emissions by 2050; enacted July 2021

Fit for 55:

Legislative tools to deliver on European Climate Law: proposed July 2021

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Fit for 55: CO2 Emission Regulation

Aimed at achieving EU's goal of net-zero carbon emissions by **2050**

Reduction's target of 100% for passenger cars and light commercial vehicles by 2035

Reduction's target of **55%** for passenger cars by 2030 and **50%** for vans by 2030

Does not apply to medium or heavy duty segment

COMPARE

Heavy Duty Fleet Emission Reduction Regulation

- Adopted August 2019
- Two binding reduction targets for OEMs:
  - 15% in 2025
  - 30% in 2030
- Commission to review and submit report by Dec 31, 2022
- New proposal expected in 2023

Indicates different, unique program for heavy duty sector

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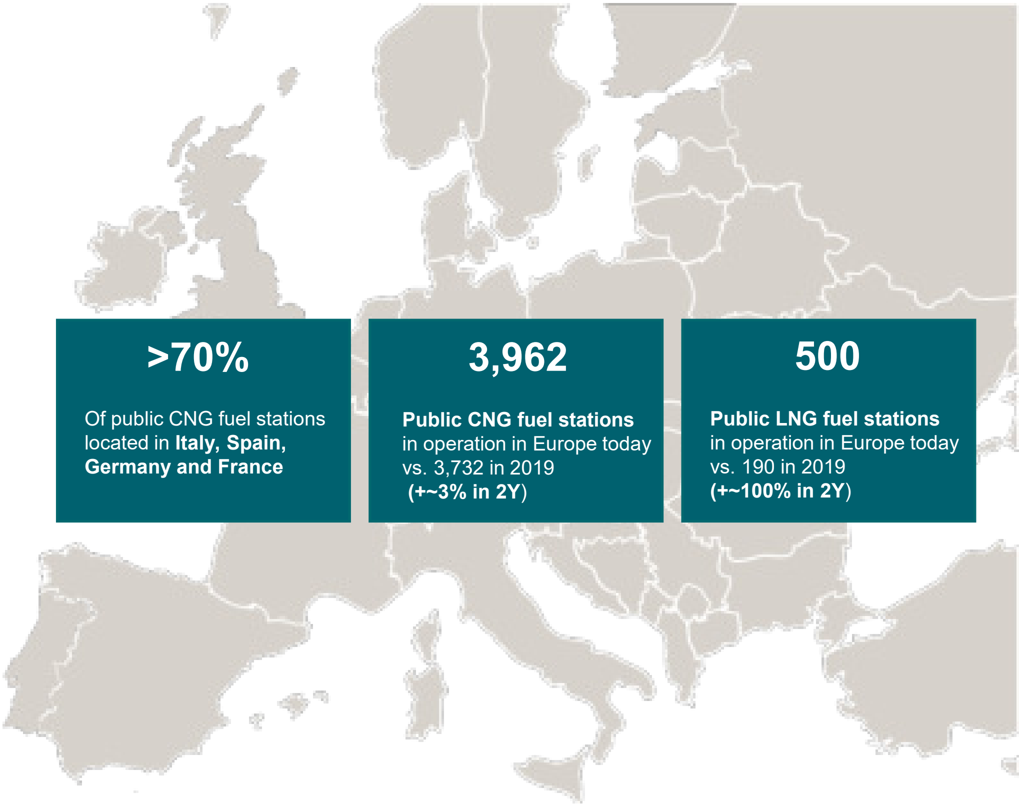
Natural gas infrastructure in EU well developed to support CNG/RNG HDV

- Advanced Fuel Infrastructure Directive adopted October 2014
- Requires one LNG refueling station at least every 400 km on TEN-T Core Network
- Retained in Fit for 55 for LNG



>70%

Of public CNG fuel stations located in **Italy, Spain, Germany and France**

3,962

Public CNG fuel stations in operation in Europe today vs. 3,732 in 2019 (**+~3% in 2Y**)

500

Public LNG fuel stations in operation in Europe today vs. 190 in 2019 (**+~100% in 2Y**)

Major engine producers introduce new, industry-changing natural gas models for heavy duty trucks, positioning for growth in RNG

SCANIA

Scania introduces new 13-litre gas engine for travel operations

- Expands engine portfolio to focus on long distance transit routes
- **Today most long-distance** intercity routes are handled by **diesel buses**
- Will continue to **expand natural gas adoption in EU** transit which today is approximately 10% adoption

"Biogas will be one of the key tools for decarbonization of heavy-duty transport – especially for intercity and long-distance operations. ***Half of Europe's heavy duty gas fleet could be powered by biogas in 2025."***

\- Jonas Strömberg, Sustainability Director, Scania Buses & Coaches

Source: Scania

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United States Regulatory Landscape

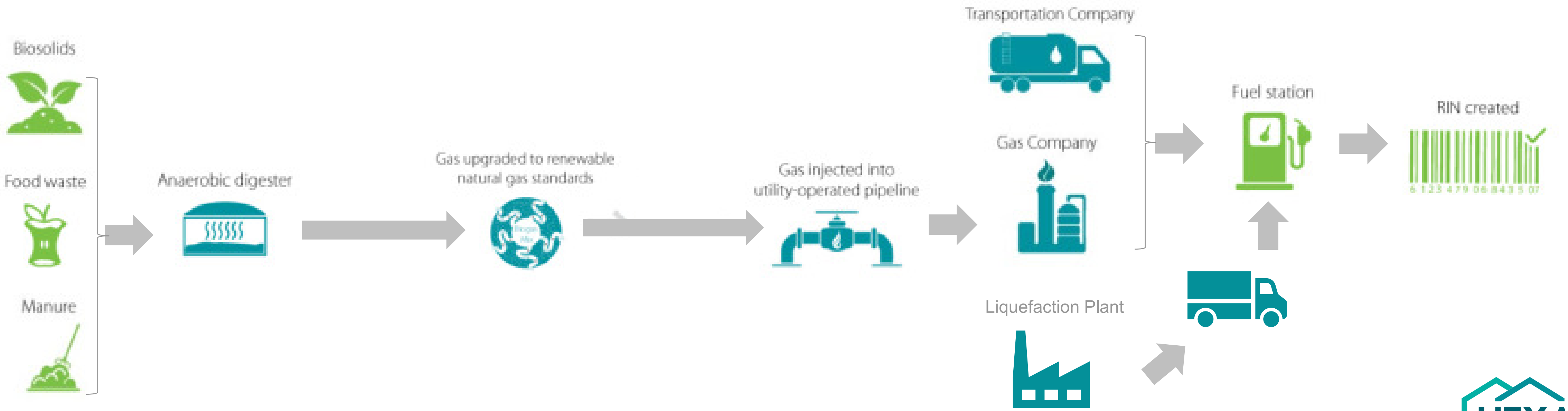
Federal government to be net zero by 2050

16 states and Puerto Rico enacted legislation establishing GHG emissions reduction requirements

EPA Renewable Fuels Standard

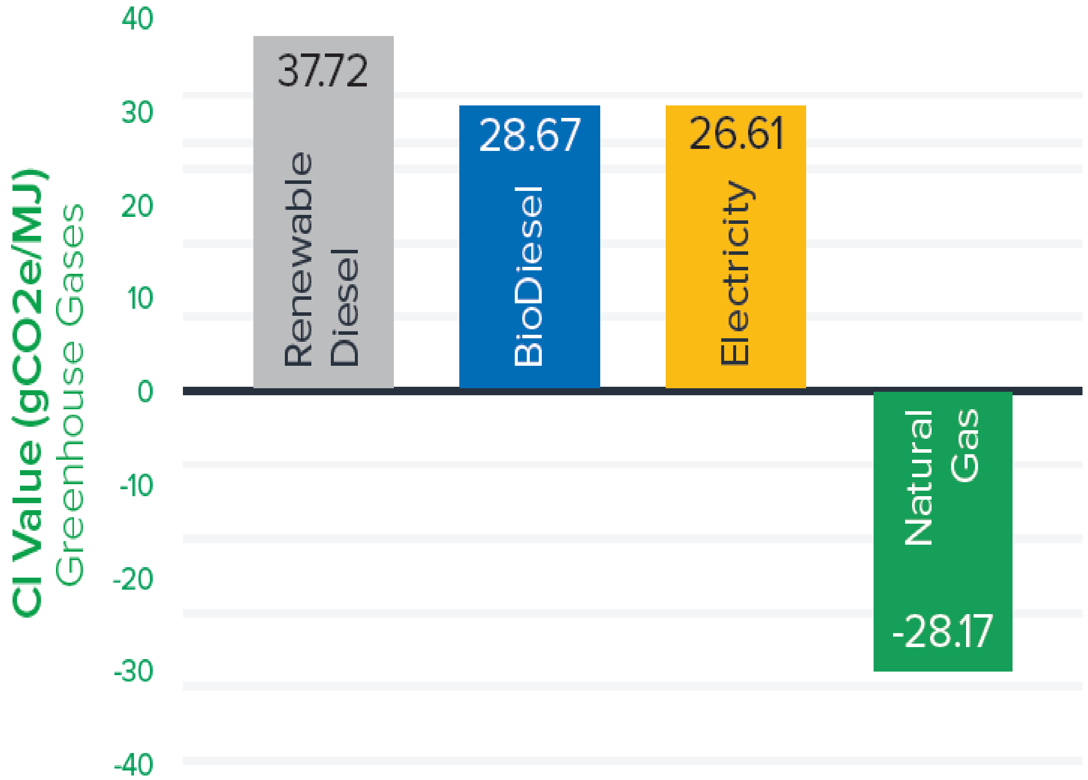
RNG Credit System

- Environmental credits are generated when RNG is used as a transportation fuel; credits are transacted between producers, brokers and obligated parties (petroleum importers, refiners and wholesalers) to reduce carbon intensity of the fuel pool
- Renewable Fuel Standard (RFS): Federal program whereby U.S. EPA sets volume requirements of renewable fuels for obligated parties
- Renewable identification numbers (RINs): Environmental credits with financial value issued under RFS; tradeable commodities; each RIN is proof that the equivalent of a gallon of renewable natural gas has been injected into a shared pipeline; RINs are the currency of the RFS
- Low Carbon Fuel Standard (LCFS): California-specific program; functions similarly to RFS/RIN program
- ***Compare:*** Limited RNG credit scheme opportunities in EU (e.g., UK and Germany); EU working to develop a framework to improve the international trade of renewable fuel transport certificates (RTFCs)



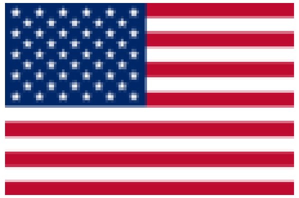
LCFS Success

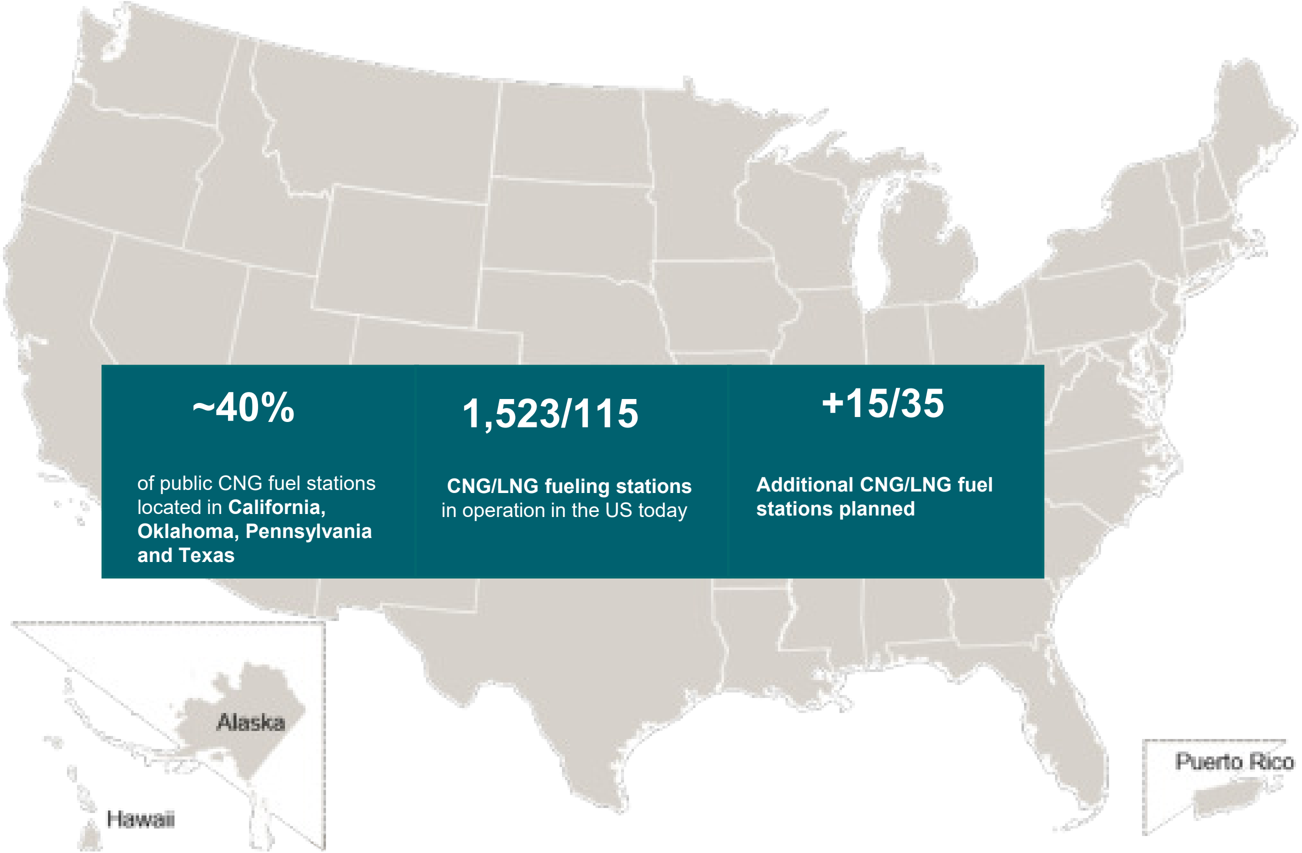
- On January 30, 2022, the California Air Resources Board (CARB) released data for its LCFS Program for Q1 to Q3 2021
- Data confirms:
  - Average carbon intensity of all of the natural gas reported in the California LCFS is negative (-28.17 gCO2e/MJ)
  - Natural gas vehicles (NGVs) operating in California provide the greatest greenhouse gas (GHG) emission benefits compared to all other transportation fuels
  - As dairy RNG supply increases, the energy weighted CI of RNG continues to drop further below zero:
    - Q1-21: -16.74 gCO2e/MJ
    - Q2-21: -35.87 gCO2e/MJ
    - Q3-21: -62.7 gCO2e/MJ



Source: California Air Resources Board Low Carbon Fuel Standard Program Q3 2021 Data

Natural gas infrastructure North America well developed to support CNG/RNG HDV





~40%

of public CNG fuel stations located in **California, Oklahoma, Pennsylvania and Texas**

1,523/115

CNG/LNG fueling stations in operation in the US today

+15/35

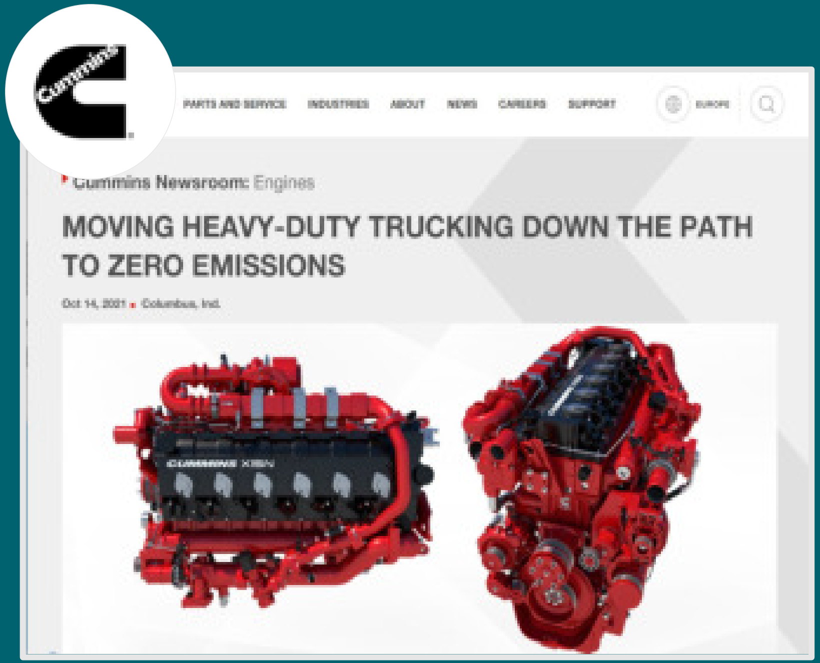
Additional CNG/LNG fuel stations planned

Source: US Dept. of Energy Alternative Fueling Station Locator, US Dept. of Transportation Office of Highway Policy Information, EUR-Lex, US Bureau of Economic Analysis, NGVA, Eurostat, EUR-Lex, World Bank

What will we accomplish today

Sufficient GHG reduction	✓
Supply potential	✓
Technology in place	✓
Supportive Regulation	✓
Does TCO support adoption today	In order for any solution to be adopted can today's fleet operate RNG profitably vs diesel and other clean energy solutions in mass

Game changer for North American class 8 truck Cummins launches 15L natural gas engine to match performance of all of todays HD diesel fleets



500 hp and 1,850 ft-lbs Torque

- **North America's most popular Heavy-Duty truck** engine platform
- Opens up **new natural gas market of 250,000** Heavy-Duty Class 8 sleeper segment
- Improved engine efficiency will further **improve total cost of ownership**

> *"We believe this natural gas option is a game changer as a **cost-competitive power option to existing diesel powertrains in heavy-duty trucking**, making it a great complement to reduce CO2 emissions."*
>
> - Brett Merritt, Vice-President On-Highway Engine Business, Cummins

 Source: Cummins

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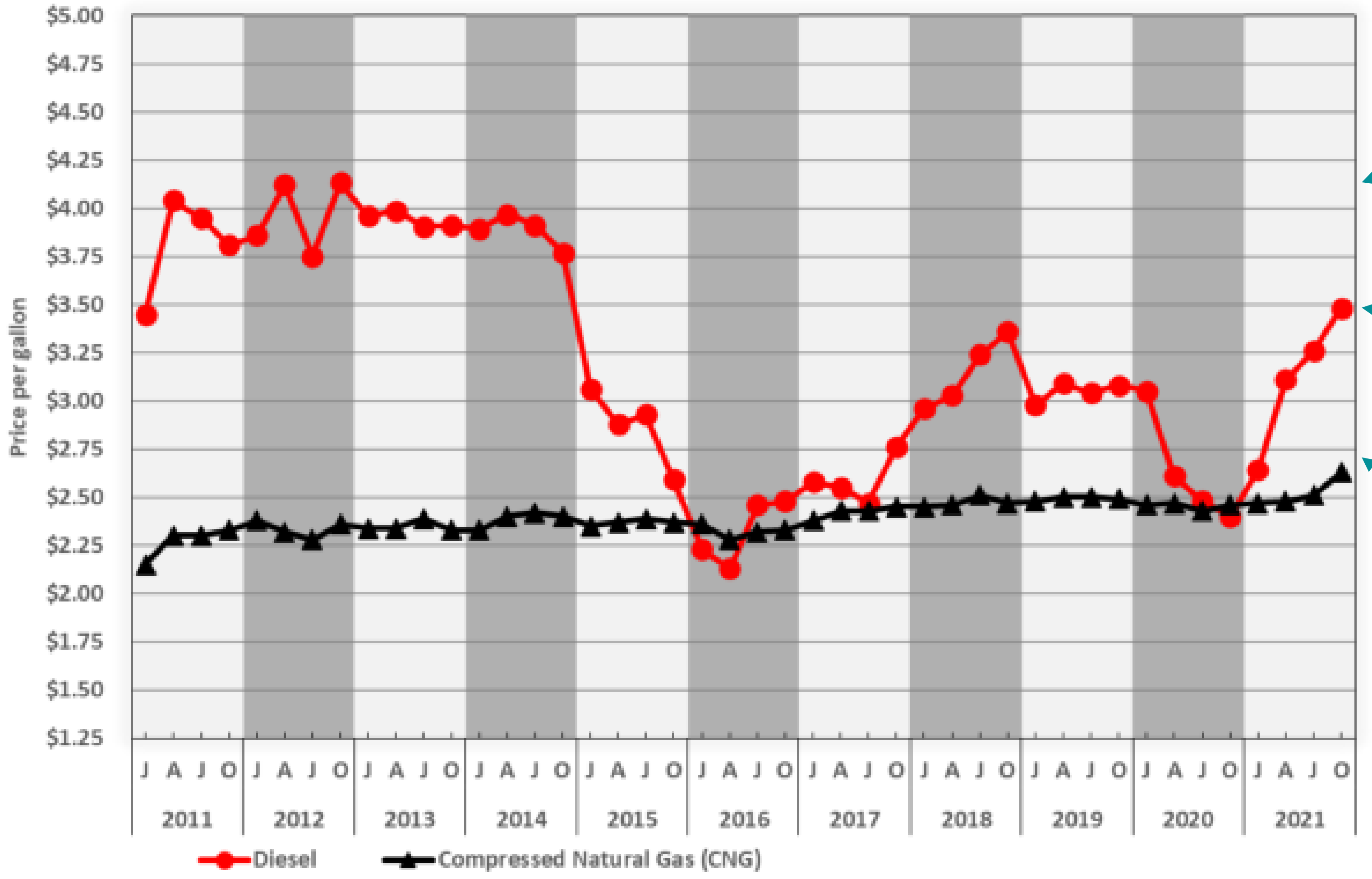
Natural Gas pump price stable vs highly volatile diesel



Today avg Diesel price is $4.10 per/Gallon per eia/Dept of Energy

October avg Diesel price was $3.48 per/Gallon per eia/Dept of Energy

October avg CNG price was $2.63 per/Gallon per eia/Dept of Energy

Source: https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_october_2021.pdf

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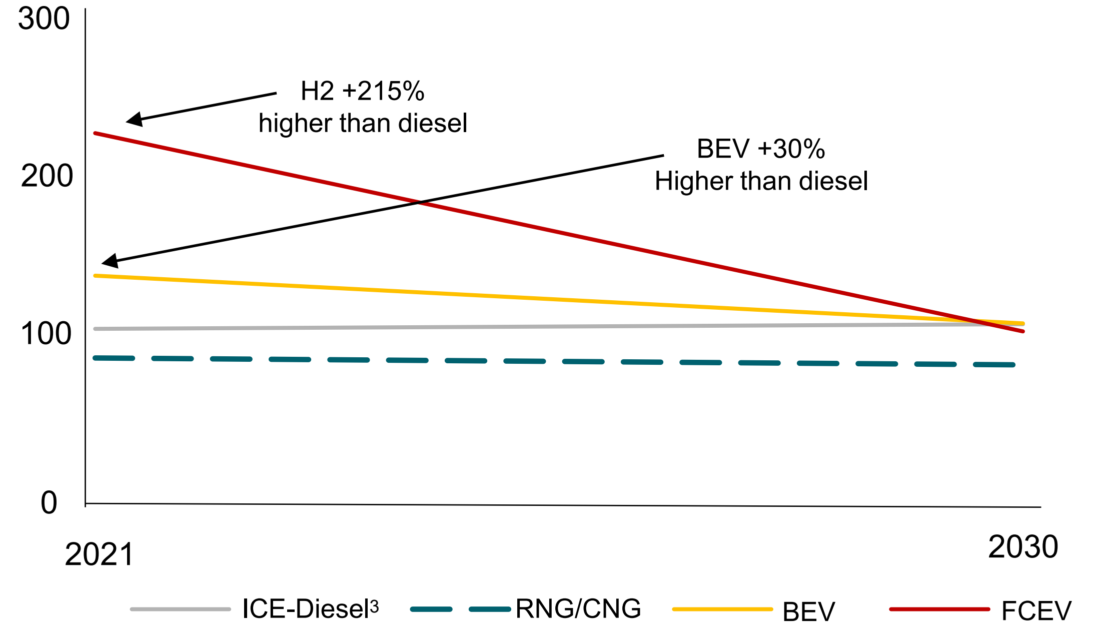
RNG has the lowest lowest operating costs for the next decade and beyond compared to other alt fuel technologies

Weight classes[2] and use cases

USA, TCO per mile indexed to ICE = 100 in 2021

HDT Long-haul



Key takeaways

RNG with organic CNG blend still best WTW GHG reduction in 2030

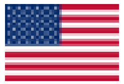
RNG's lower operating costs, readily available OEM platforms, significant refueling infrastructure and technology that matches the performance of todays diesel truck **RNG is the class 8 long-haul solution 2030 and beyond**

1. Based on well-to-wheel calculations, Source: CARB and Third-Party Source
2. Weight classes : US: HDT: Class 7, 8 (>12t), MDT: Class 4-6
3. Difference negative (US), since diesel assumed with increasing blend shares of renewables – in 2050 100% renewables, both from biomass and synthetics

RNG has the potential to replace diesel and is complementary to fuel cell and battery electric in the long term

ICE-Natural gas RNG and fossil, gaseous and liquefied | ICE-Diesel from fossils and bio | BEV | FC

Future Scenario **Supportive regulation** **Full potential**



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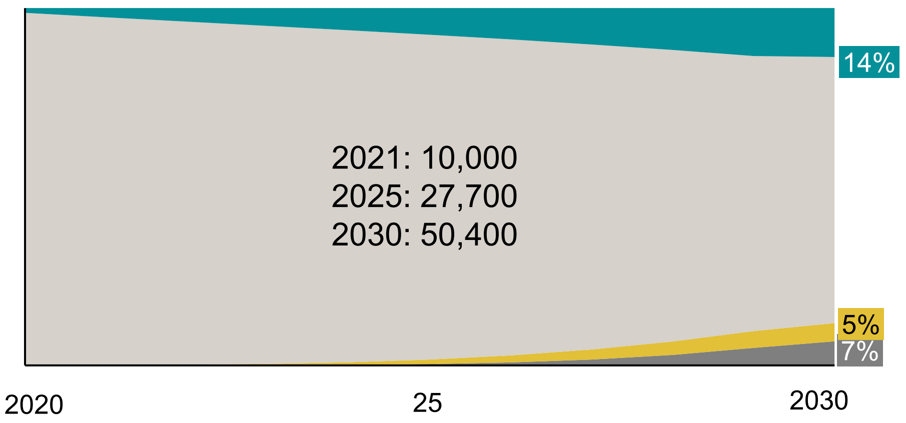
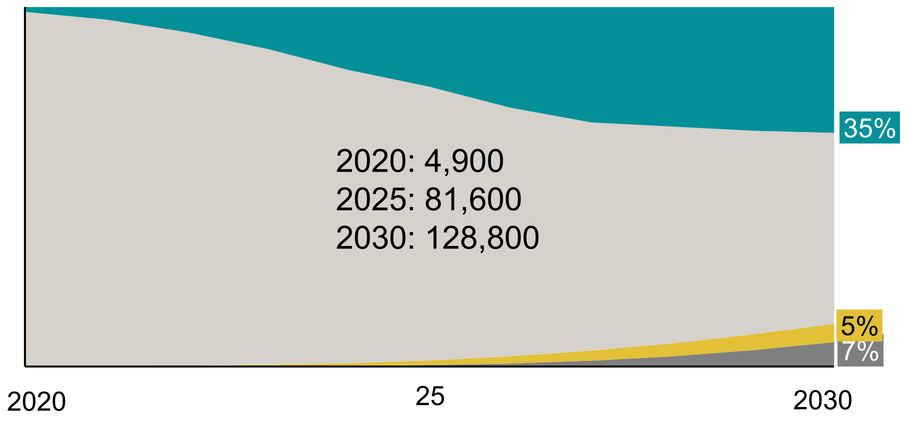
vehicles





Supportive regulation

- Regulatory support extended to 2030 and incentives continue (RNG=CNG)
- Less than 10% of potential biomass needs to be converted into RNG to acheive low case scenario of 14% pure RNG Adoption

Full potential

- Regulatory support extended post 2030 and W2W regulation for OEMs introduced
- OEM launch push towards CNG/RNG powertrains, spend R&D budget and infrastructure grows significantly

Source: IHS Markit, ACT Research, Third party consultant

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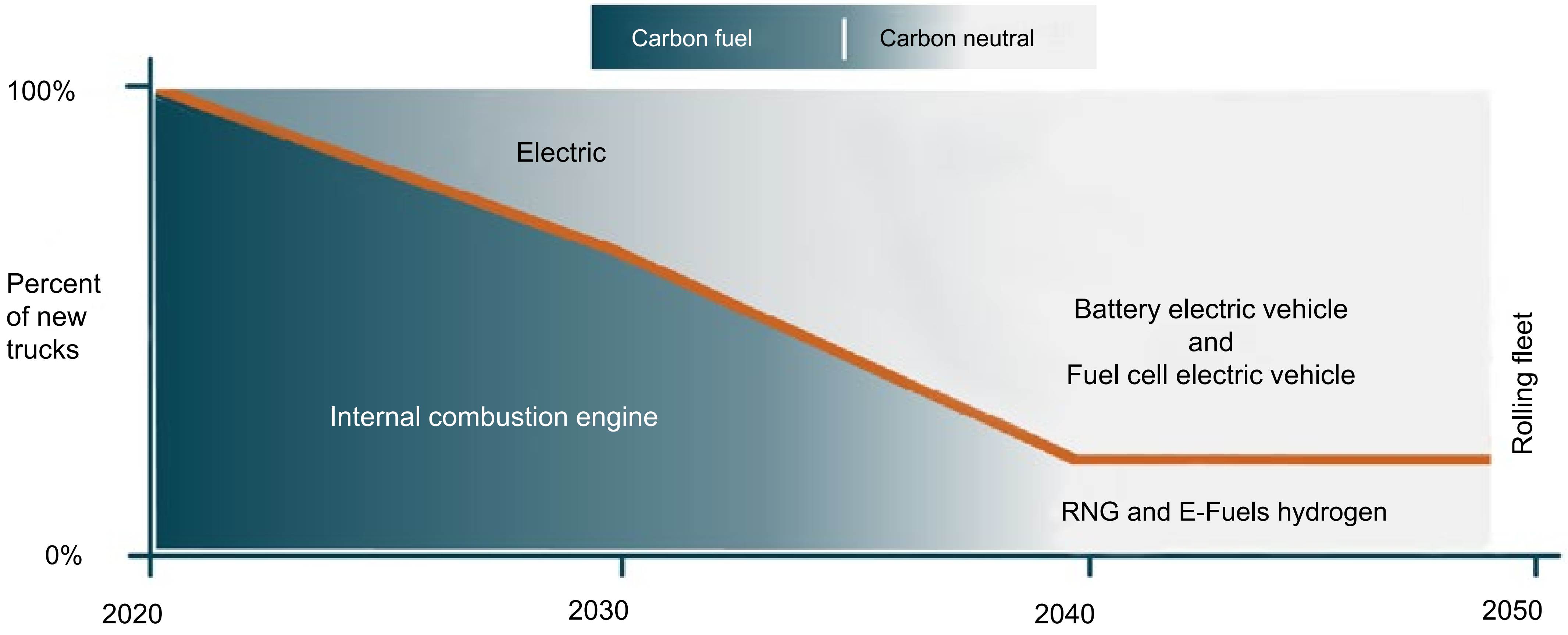
OEMs conclude that for the HD truck segment the most likely long-term solution will be a multi-fuel strategy



Source: H2Accelerate Whitepaper (Daimler, Iveco, OMV, Shell, TotalEnergies, Volvo Group)

Summary: RNG's full potential reduces $CO_{2\text{-eq}}$ emission & TCO

RNG full potential analysis

No supply constraints	**~65%**	RNG supply potential required to cover 100% of commercial transport in the EU, US by RNG
	<10%	RNG supply potential required to cover 15%[1] RNG share in commercial transport
Highest carbon abatement potential	**200%**	$CO_{2\text{-eq}}$ emissions savings of RNG from manure compared to trucks with fossil diesel
	60%	RNG can be the biggest $CO_{2\text{-eq}}$ emission reduction lever of MDT & HDT sold 2022-2030
RNG is cost competitive today	**<15%**	Lower TCO for RNG trucks to ICE-diesel resulting in savings for fleets with current RNG incentives
	2040 and beyond	RNG remains competitive vs. Diesel and BEV and FCEV well beyond 2040
Mature CNG/LNG technology	**15+**	OEMs with mature offering in CNG , incl. Freightliner, PACCAR, Volvo, and more
	+10%	Parc share in MDV/HDV 2030 targeted by ambitious fleet operators to reduce CO_2 emissions

1. Assumes 30% sales share of RNG in 2030 and 13% parc RNG share

Source: Third party consultant - H2 Accelerate Whitepaper (Daimler, Iveco, OMV, Shell, TotalEnergies, Volvo Group)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Whitepaper
The need for hydrogen trucking

A whitepaper setting out the underlying arguments in favour of the use of hydrogen to decarbonise long-haul trucks. This paper discusses the role of hydrogen in facilitating rapid and enhanced renewable energy deployment, and the need for hydrogen as the only zero-carbon zero-emission fuel in the heavy-duty trucking sector which can provide a combination of fast refuelling and very long range between refuels.

This paper was published by the H2Accelerate Collaboration in July 2021 as the first in a series of whitepapers in support of the use of hydrogen in long-haul trucking.

The H2Accelerate collaboration

The H2Accelerate collaboration has been formed between Daimler Truck AG, IVECO, OMV, Shell, TotalEnergies, and Volvo Group to work collaboratively to develop the evidence base and public funding programs which can help move Europe towards a commercially viable hydrogen trucking system. Each of these major industrial players, from both the fuel supply and trucking sectors, have made their own organisational commitments to achieving net zero carbon in line with Europe's ambitious decarbonisation targets under the Paris climate agreements.

The H2Accelerate companies are agreed that achieving the decarbonisation of the heavy-duty trucking sector will require the use of hydrogen as a fuel for many of the vehicles used by the continent's vehicle operators.

This paper will set out the basis for this conclusion. Two aspects of the case for hydrogen are considered:

- The role of hydrogen in enabling overall energy system decarbonisation (providing long-term energy storage to balance the energy system and allowing the transport of low carbon energy across the globe).
- The need for hydrogen as the only zero-carbon zero-emission fuel in the heavy-duty trucking sector which can provide a combination of fast refuelling and long ranges between refuels.

These two arguments lead to the conclusion that hydrogen as a fuel for trucking is essential for the decarbonisation of the trucking sector which causes 6%[1] of the total European CO2 emissions. This conclusion supports the case for public sector support of the early roll-out and industrialisation of the hydrogen trucking sector in Europe in the period from now to 2030. The H2Accelerate collaboration aims to orchestrate the roll-out by leveraging the expertise and commitments of key truck manufacturing and hydrogen infrastructure players.

[1] European Commission (2019) *Reducing CO_2 emissions from heavy-duty vehicles*

The role of hydrogen in sustainable energy systems

Achieving the European Green Deal target of becoming the world's first climate-neutral continent by 2050 will require deep cuts to emissions across all aspects of the economy. Europe has so far achieved the majority of its emissions reductions by decarbonising electricity generation, principally through reducing coal fired generation and increased deployment of hydro, wind, and solar projects, which generated 28% of gross electricity consumption in the EU-27 in 2019[2].

Further cuts will require a massive expansion in the deployment of renewable energy generation, to provide the primary energy for the electricity sector, as well as much of the energy needs for heat, industry and transport. This alongside different combinations of other technologies such as carbon capture and storage, and substantial increases in overall energy efficiency, are required in all the recognised scenarios for achieving a net zero emissions continent.

The challenge faced in using renewable power sources to further decarbonise the energy sector is that renewable sources such as wind and solar are inherently intermittent, and the quantity of renewable energy generation can be expected to fluctuate on both a short-term, and seasonal timeframe. Resolving the imbalances created by this massive penetration of renewables will require storage of energy on timescales of weeks and months to avoid wasting large quantities of energy every year. While many renewable energy storage options will be available, only hydrogen-based options can be deployed at the scale required to achieve this seasonal energy balancing, as shown in the diagram below.

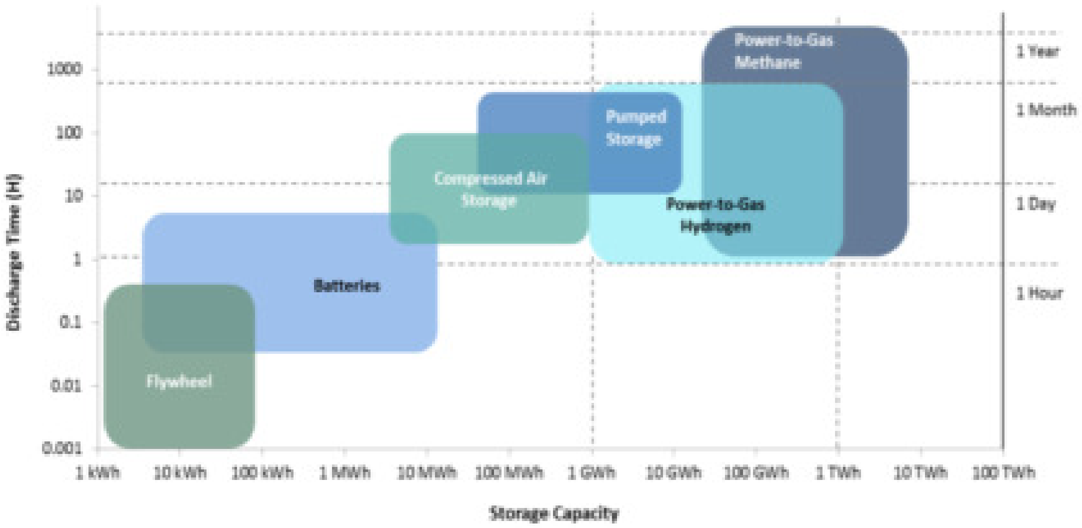

Figure 1: Storage capacity and discharge time of different energy storage mechanisms[3]

[2] Eurostat (2021) Wind and water provide most renewable electricity

[3] European Commission (2018) A clean planet for all: *A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy*

To meet the challenge of intermittency, hydrogen can be produced using electrolysis powered by excess renewable electricity and used in many different sectors as a clean energy vector. Unlike other storage options, hydrogen can be stored over long periods of time and scales compatible with seasonal energy storage, making it a leading candidate to enable the seasonal balancing of renewable power sources.

At a large scale, it becomes cost-effective to store hydrogen in salt caverns. This solution is compatible with European geography, and a number of potential hydrogen storage sites have been identified across Europe, including in Germany, the Netherlands, Norway, Denmark, and Poland. It is estimated that Europe has the technical potential to store 84.8 PWh[4] of hydrogen in bedded salt deposits and salt domes and is therefore well equipped to implement the seasonal storage of green hydrogen in large-scale geological formations, in order to provide grid-balancing functions. An additional advantage of hydrogen is that once generated, it can be moved by ship (as compressed or liquid hydrogen, or in carriers such as ammonia and liquid organic hydrogen carriers) or pipeline around the world at a reasonable cost. This means countries with a large land mass and good renewable resources (deserts coastal regions, large windy plains etc.) can become exporters of large quantities of low-cost hydrogen. A recent analysis by the Hydrogen Council suggested that this international bulk movement of the fuel will only add between 10-30% to the delivered cost of the fuel[5]. This means that hydrogen can become the storable, transportable fuel of the future progressively displacing the role that fossil fuels play in today's energy system.

Given that hydrogen appears to be the most promising long-term energy store and a means for transporting bulk quantities of renewable energy around the world, the next question is where the hydrogen should be used. Here, the value of hydrogen in displacing different energy sources is relevant. The transport sector, particularly hydrogen trucks, is an application where hydrogen becomes cost effective at displacing fossil fuels at a relatively high cost of hydrogen production compared with other applications, and hence is an obvious first target for the fuel.

Within the transport sector, the only other fully zero emission option is the use of battery electric vehicles charged using renewable electricity. Whilst battery electric vehicles are clearly emerging as promising options for certain applications, particularly for smaller cars, vans, and short and medium haul trucks, the section below will demonstrate that for larger, longer-range trucks, where flexibility and high productivity is required, hydrogen is a very attractive solution compared to battery alternatives.

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[4] Caglayan et al (2020) *Technical potential of salt caverns for hydrogen storage in Europe*

[5] Hydrogen Council (2020) Path to hydrogen competitiveness: A cost perspective

The use of hydrogen in trucking

The decarbonisation of long-range and heavy-duty trucking is one of the most difficult challenges in reaching net zero carbon emissions from the road transport sector. Emissions from lorries, buses and coaches are estimated to account for 6%[6] of total EU emissions, of which the vast majority comes from the trucking sector.

Truck transport can be divided into four categories, based on the utilisation and range of the vehicles.

1. Short haul transport that largely returns to a depot location overnight.
2. Medium haul transport within a restricted geographic region, that largely returns to a depot location overnight.
3. Long-haul transport in line traffic with repeated, predictable routes between set destinations.
4. Long-haul transport, travelling by motorway for the majority of the journey, often internationally over multi-day trips. These trucks seldom stay at the same location overnight.

While heavy-duty long-haul trucks comprise only 12% of the European fleet, they are responsible for 41% of road freight emissions due to their high payload, weight and distances travelled[7]. For these trucks, shorter ranges and slow refuelling has a significant impact on both the cost of transport and logistics operations. This leads to a need for a zero-emission alternative to current diesel vehicles that can achieve a high vehicle range, with fast refuelling/recharging, high payload, and an extensive supporting infrastructure network that is harmonised across Europe.

There are three potential solutions to achieve zero emission long-haul trucks, which result in zero CO2 tailpipe emissions:

1. Hydrogen fuel cell trucks
2. Battery trucks with stationary charging
3. Battery trucks with catenary charging

While biofuels, power-to-X type fuels, or hydrogen internal combustion engines may be able to reduce CO2 emissions from trucking in the short term, these solutions do not mitigate the NOx and particulate emissions associated with internal combustion engines. Hydrogen fuel cell or battery-based solutions will therefore be required in the long term.

Currently, battery trucks are not able to compete with hydrogen fuel cell alternatives on either a range or refuelling time basis. While fast charging for battery alternatives is technically feasible, this solution adds significant operating cost due to the cost of fast charging, resulting in a higher total cost of ownership when compared with hydrogen solutions in certain applications.

[6] European Commission (2019) Reducing CO2 emissions from heavy-duty vehicles

[7] Shell International B.V. (2021) *Decarbonising road freight: Getting into gear*

Conversely, hydrogen trucks will be able to operate in a similar way to diesel vehicles, through fast refuelling (under 15 minutes) and similar range (ranges in excess of 800km even for the heaviest loads, depending on the specific technology used), offering operational simplicity and reduced total cost of ownership compared with battery alternatives with fast charging. Unlike battery-based alternatives, hydrogen solutions are expected to meet customer needs within the long-haul trucking space, and the companies driving H2Accelerate are prepared to bring them to market in the near-future.

An additional challenge of the range of battery trucks operating in certain long-haul trucking use cases, is the need for an increased number of charging points compared to hydrogen refuelling stations. This further presents operational challenges in long haulage due to the comparatively low maximum radius that can be travelled by a truck from a charging point.

Some argue that the challenges of range for battery trucks could be resolved through the installation of a network of catenary lines allowing vehicles to charge whilst driving on major road networks throughout Europe. However, this requires European governments to commit to a large-scale long-term pan-European infrastructure project, at significant technical and financial risk, and delaying the emissions reductions achieved by decarbonising heavy transport while infrastructure is developed. There are also questions over the cost of upgrading electricity networks to provide the power which will be required by these catenary networks to ensure a sufficiently rapid charging rate for the batteries (without requiring charging along the entire length of the road network), and whether sufficient network utilisation will be achieved to repay infrastructure investments. Finally, in practice (as with railways), there will always be areas of the road network which are not covered by the catenary system meaning that many users will require an alternative that is able to operate in areas that are not covered by the catenary system.

By contrast, the hydrogen providers involved in H2Accelerate plan to roll out hydrogen refuelling infrastructure across key strategic routes and expand from these routes to provide sufficient coverage to support continent-wide hydrogen trucking for Europe. These stations will have a high capacity to refuel fleets of hydrogen trucks using renewable hydrogen in under 15 minutes and will be modular so that they can easily expand with increasing penetration of hydrogen trucks. Hydrogen has the additional advantage here that the long range of the hydrogen truck reduces the number of refuelling stations needed compared with battery charging stations to cover the same overall length of road.

For battery truck options, it is highly unlikely that there will be sufficient charging network coverage and/or range to meet the needs of all truck users to deliver on climate targets within the agreed upon timescales. As a result, the view of the H2Accelerate truck OEMs is that the future mix of technologies used in the trucking sector will be as shown in the graphic below, with the hydrogen fuelled truck providing the longer-haul, heaviest-duty routes.

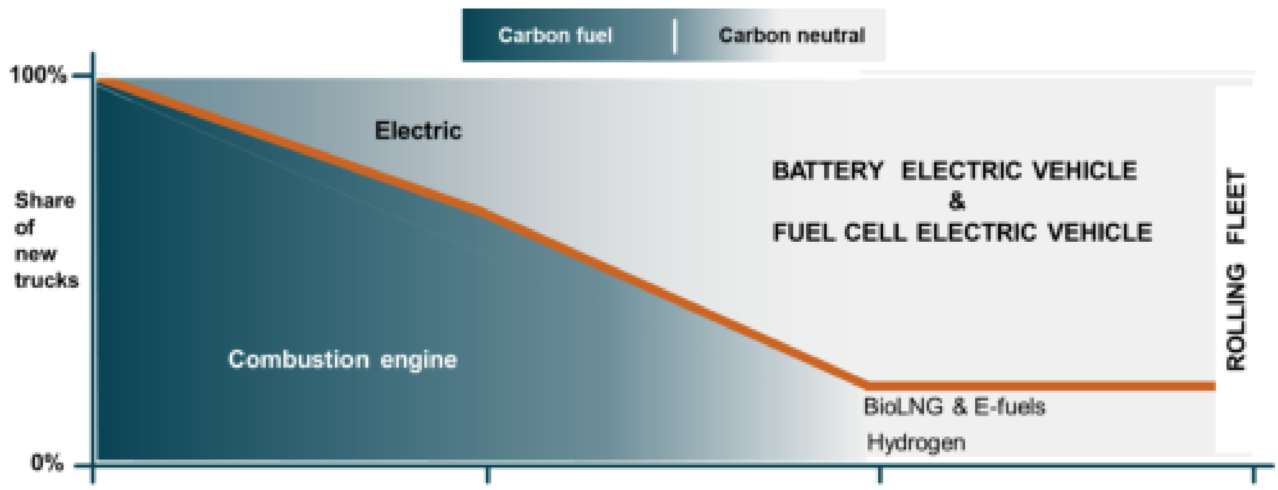

Figure 2: Transition of trucking to zero emission alternatives between 2020 and 2050

In the long term, the hydrogen-based solution has the additional benefit of being much more compatible with autonomous vehicles. In this future scenario, where self-driving trucks are able to operate autonomously on a 24/7 basis, charging time for battery vehicles will have an untenable impact on the business case.

Conclusions

The member companies of the H2Accelerate collaboration: Daimler Truck AG, IVECO, OMV, Shell, TotalEnergies, and Volvo Group, are fully aligned in their view that:

- Hydrogen is required to manage imbalances in energy generation and consumption in the renewable-dominant energy system of the future. It is also one of the very few options for bulk transport of renewable energy around the world.
- Hydrogen can solve the challenge of decarbonising the heavy-duty long-haul sector, for which there are essentially no other viable options which can work for all users.

As a result, it is reasonable to consider hydrogen a required fuel for the trucking sector of the future and to start accelerating the industrialisation of hydrogen fuel cell truck technology and the associated refuelling network and field support mechanisms. The H2Accelerate collaboration is committed to act now to facilitate the rapid deployment of hydrogen trucks and the required supporting infrastructure at scale, to achieve an acceptable ownership cost proposition and easy operation for end users. This will help facilitate the penetration of renewable energy generation. By 2030, the infrastructure deployed will allow hydrogen to become a key solution for long-haul road transport across Europe, allowing the sector to achieve climate goals.