The Future of **Hydrogen & RNG** in Canada

Part 3: Technology & Market Readiness of Hydrogen

June 16, 2021

PEMBINA institute

Opening remarks

Simon Dyer

Deputy Executive Director

Pembina Institute

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Leading Canada's transition to clean energy

The Pembina Institute is a non-profit think-tank that advances a prosperous clean energy future for Canada through credible policy solutions.

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Moderator

Tahra Jutt

Director, Clean Economy (B.C.)

Pembina Institute

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Speaker

Dr. Simon Bennett

Technology & Investment Analyst, Supply and Investment Outlooks Division

International Energy Agency

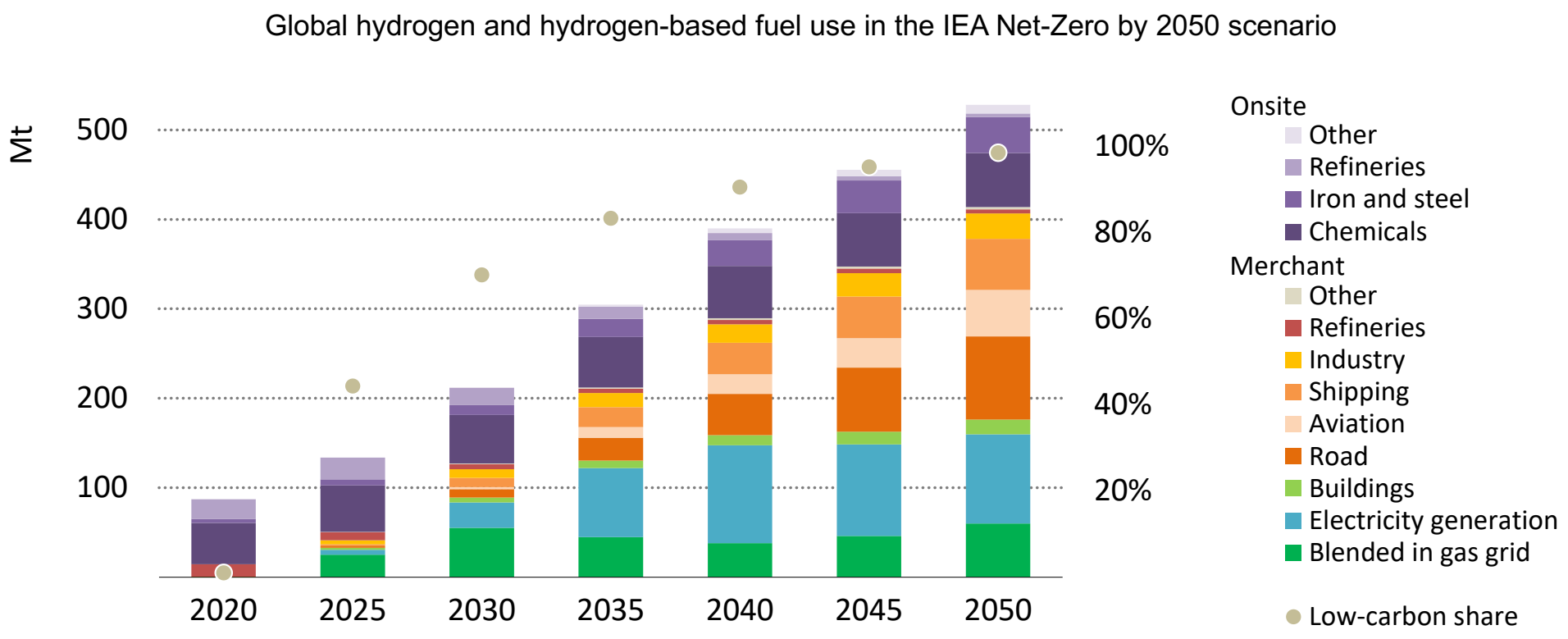
Hydrogen prospects

Pembina Hydrogen Webinar, 16 June 2021

Simon Bennett, International Energy Agency

International Energy Agency

IEA net-zero by 2050 pathway: hydrogen use expands rapidly



Today, hydrogen use is mostly for refineries and heavy industry, and the associated CO_2 emissions are large. The future opportunity lies in a much wider range of sectors, but it must all be low-carbon to meet climate goals.

Why hydrogen?

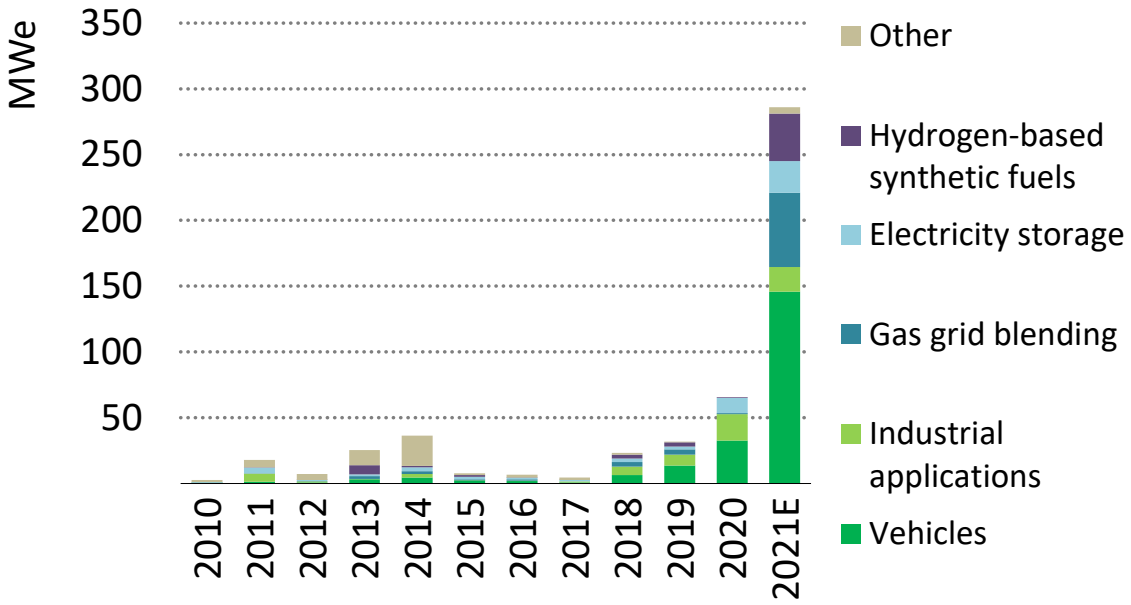
- It produces no CO_2 when used
- It is a leading solution for several critical and interrelated challenges
    1. How to reach very high levels of variable renewable electricity through long duration storage and flexible power generation
    2. How to replace coal and gas in refining, steel, chemical production and heat cement plants
    3. How to avoid the costs and challenges of electrifying nearly all land transport
    4. How to maintain the benefits of market-based trade in energy, to balance long-term and short-term regional imbalances
    5. How to allow air transport to continue in a net-zero world without very high levels of carbon removal and bioenergy
    6. How to sidestep the challenges of full end-use electrification (including expanding the power grid to meet peak heat demand, decommissioning gaseous fuel infrastructure and switching all customers to electrical equipment).

Why not hydrogen?  Efficiency losses, parallel infrastructure, huge investment needs, low capital efficiency, complicates the electrification narrative, competes with lifestyle changes

So where are we today?

- Momentum is unprecedented. If this is just another hype cycle, it's a very big one!
- In the last few years, 12 countries plus the EU have published hydrogen strategies. 18 are under development
- Hydrogen companies have raised around $8 billion in equity since 2019
- Record levels of project development and record electrolyser sizes commissioned
- Electrolyser manufacturing capacity is rising from around 3 GW to around 9 GW
- New CCUS projects for hydrogen announced

Electrolyser additions for clean energy production



World Energy Investment 2021

- Costs of low-carbon hydrogen remain high compared to natural gas (1.5-7x), mainly due to input costs

Where next?

- IEA first annual Global Hydrogen Review – September 2021

- High-level shopping list:

1. Policies and projects that create dependable and bankable demand for low-carbon hydrogen equipment (electrolysers, storage, CO_2 storage, refuelling stations)

   Existing hydrogen demand is a good place to start, especially if new infrastructure and value chain contracting can be minimised
2. Technology neutral certification for low-carbon gases, ideally with international harmonisation
3. Long-term strategies for existing gas infrastructure and heating for buildings
4. Test multiple technology and regulatory configurations globally

Speaker

Dr. Jeff Goldmeer

Emergent Technology Director - Decarbonization

GE Gas Power

16 June 2021

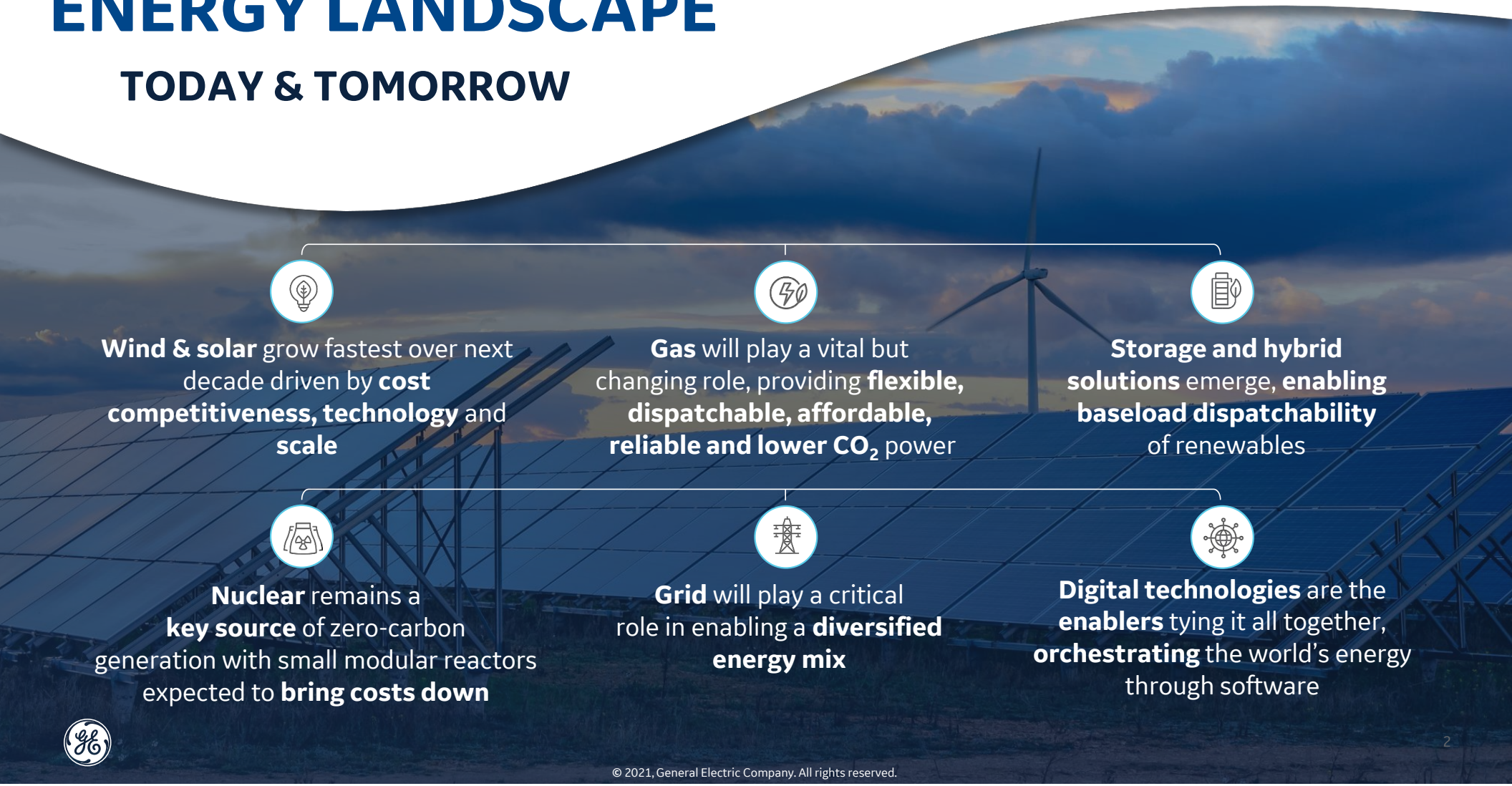
Decarbonizing our energy ecosystem with gas turbines

The Future of Hydrogen in Canada, Market Opportunities & Tech Readiness

Dr. Jeffrey Goldmeer
Emergent Technologies Director – Decarbonization

ENERGY LANDSCAPE

TODAY & TOMORROW



Wind & solar grow fastest over next decade driven by **cost competitiveness, technology** and **scale**

Gas will play a vital but changing role, providing **flexible, dispatchable, affordable, reliable and lower CO_2** power

Storage and hybrid solutions emerge, **enabling baseload dispatchability** of renewables

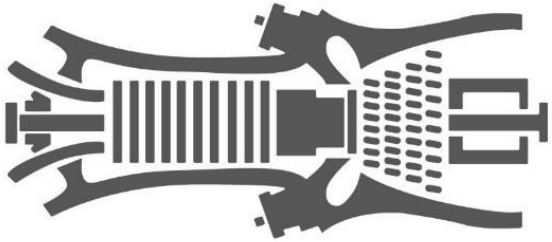
Nuclear remains a **key source** of zero-carbon generation with small modular reactors expected to **bring costs down**

Grid will play a critical role in enabling a **diversified energy mix**

Digital technologies are the **enablers** tying it all together, **orchestrating** the world's energy through software

Decarbonizing gas power* … a range of options

Pre-combustion



Post-combustion

Use a zero or carbon neutral fuel

- Hydrogen (blue, green, pink)
- Synthetic methane
- Renewable methane
- Biofuels
- Ammonia

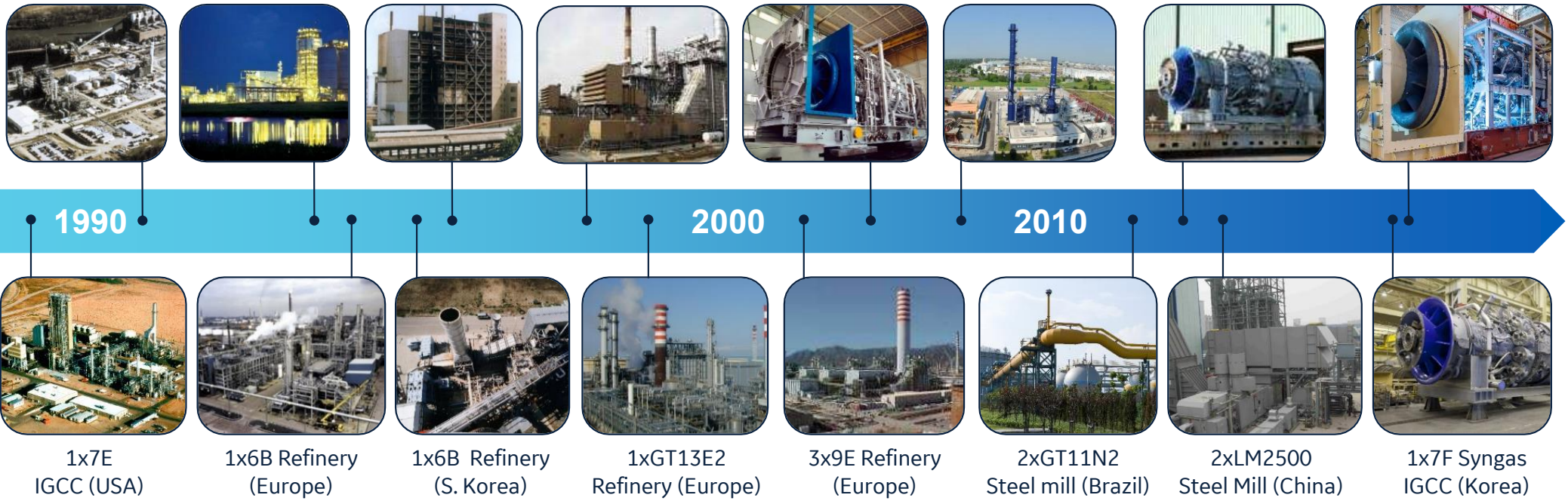
Remove carbon from the plant exhaust

- Carbon capture (liquid solvents)
- Carbon capture (solid sorbents)
- Oxy-fuel cycles

Gas turbines offer multiple options to achieve lower or zero carbon emissions

*Decarbonization as used herein is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis | Source: IEA WEO 2020

Decades of experience with hydrogen and similar low BTU fuels

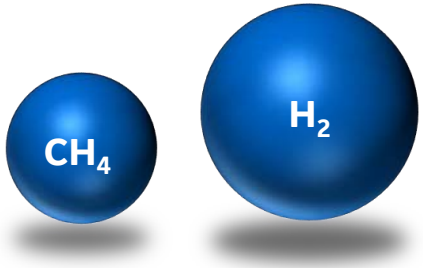


More than 75 gas turbines with more than 6 million operating hours

Use of hydrogen as a gas turbine fuel requires system changes

Fuel System

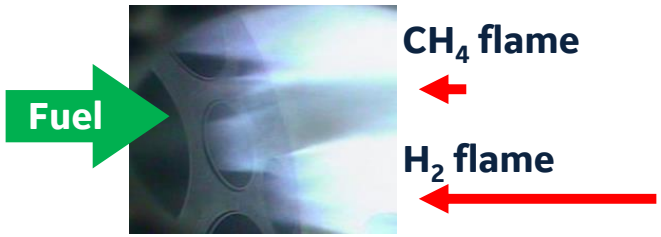
Methane (CH_4): 912 lb/ft^3
Hydrogen (H_2): 275 lb/ft^3



To deliver the same energy content, hydrogen requires 3X more volume flow

Combustion System

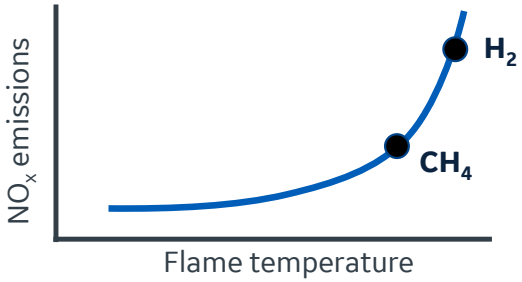
Methane (CH_4): ~30–40 cm/sec
Hydrogen (H_2): ~200–300 cm/sec



Hydrogen flames may increase risk of damage to combustion hardware

Emissions Aftertreatment

Methane (CH_4): ~3,565 °F
Hydrogen (H_2): ~4,000 °F



Operating on hydrogen may increase NO_x emissions

Operating a gas turbine on blends of hydrogen or on 100% hydrogen may require changes to key power plant systems, but this has been successfully demonstrated

Commercial projects using hydrogen

Existing units are capable of operating on H_2 blends

- Four GE 7F gas turbines operated on a **blend** of **hydrogen** with natural gas
- Post blending, the fuel contained ~ 5% (by volume) hydrogen

High H_2 fuel commercial operation

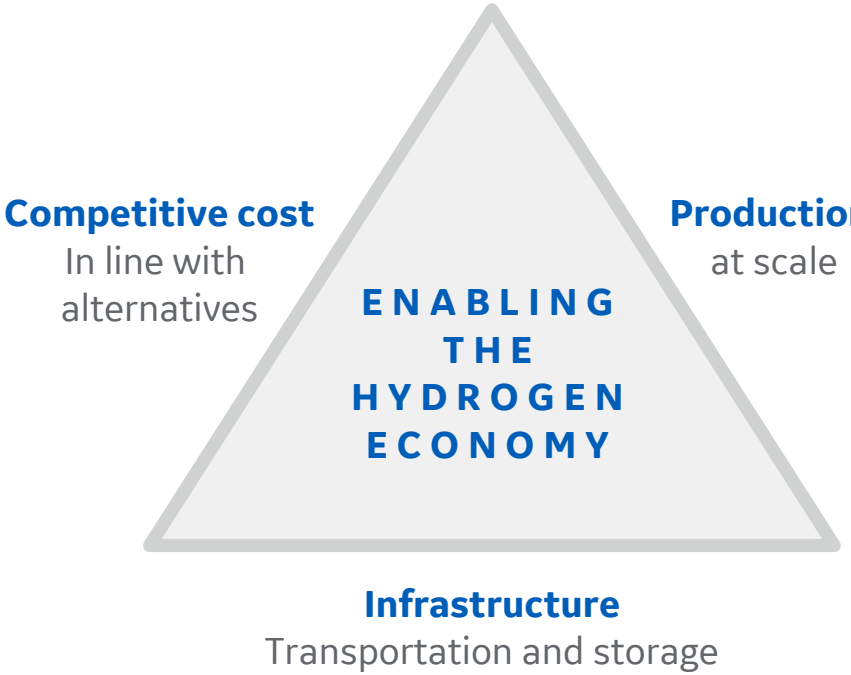
- A 6B gas turbine has been operating for 20+ years on a high-hydrogen fuel
- The hydrogen composition has varied from **70%** and **95%** (by volume)

Utility-scale gas turbine operation on H_2

- Long Ridge Energy intends to begin blending hydrogen in their **new 7HA.02** gas turbine
- The owner's plan is to transition the plant to 100% hydrogen in 10 years

Gas turbines (both new and installed units) can be configured to operate on hydrogen

Considerations to make hydrogen a competitive power gen fuel



TODAY

70M tons of H_2 produced/year

> 99% is **grey** hydrogen

FUTURE

2050 forecast for **green** and **blue** hydrogen for power generation is ~3X more than all hydrogen produced today*

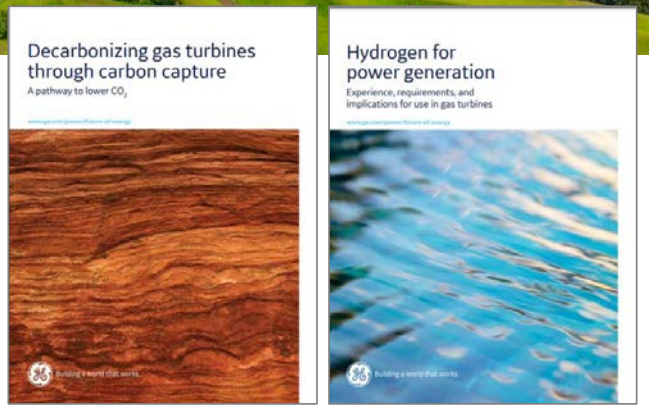
- **Grey:** Reforming natural gas
- **Blue:** Reforming natural gas + CCUS
- **Green:** Electrolysis of water with renewable power

Using hydrogen as a gas turbine fuel requires solving the trilemma of affordability, reliability, and sustainability

*bp Energy Outlook, Hydrogen,

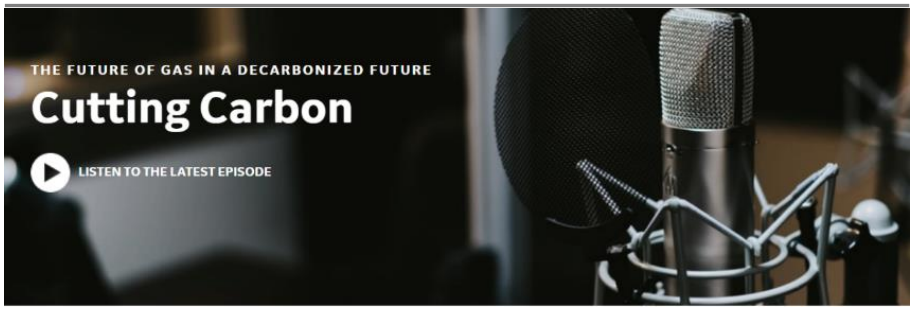
Additional information available to continue the learning...

The Future of Energy ... building a world that works



https://www.ge.com/gas-power/future-of-energy
https://www.ge.com/gas-power/future-of-energy/hydrogen-fueled-gas-turbines

Cutting Carbon: a conversation about our energy future



Apple Podcasts
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Google Podcasts
amazon music
Amazon Music

https://www.ge.com/gas-power/future-of-energy/cutting-carbon

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Speaker

Traci Kraus

Director, Government Relations

Cummins, Inc.

Cummins and Hydrogen

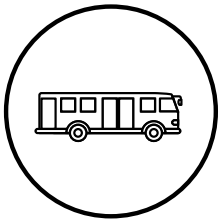
Traci Kraus

June, 2021

We serve many markets and applications


Heavy-duty Truck

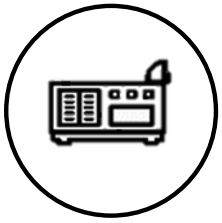

Medium-duty Truck

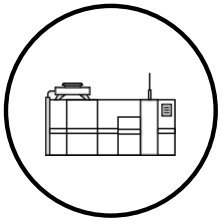

Bus


Construction


Oil & Gas


Fire & Emergency


Power Generation

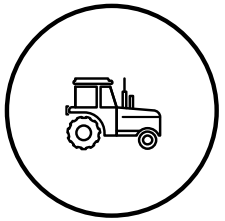

Electrolysis

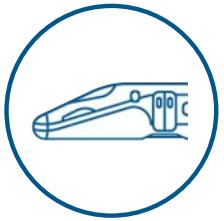

Marine


Mining


Light-duty Automotive & Recreational Vehicle


Defense

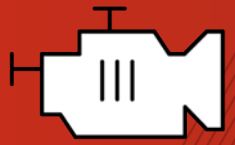

Agriculture


Rail

This is not an exhaustive display of Cummins-powered markets. Please refer to cummins.com for the most updated product information.

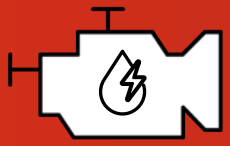
Cummins is a global technology leader with a broad portfolio of power solutions

BATTERY ELECTRIC

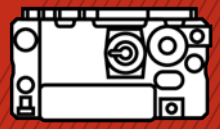


ADVANCED DIESEL

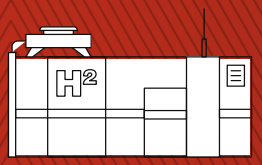
NATURAL GAS



HYBRID



FUEL CELL ELECTRIC



ELECTROLYSIS

PLANET 2050 aspirational targets

COMMUNITIES ARE BETTER BECAUSE WE ARE THERE

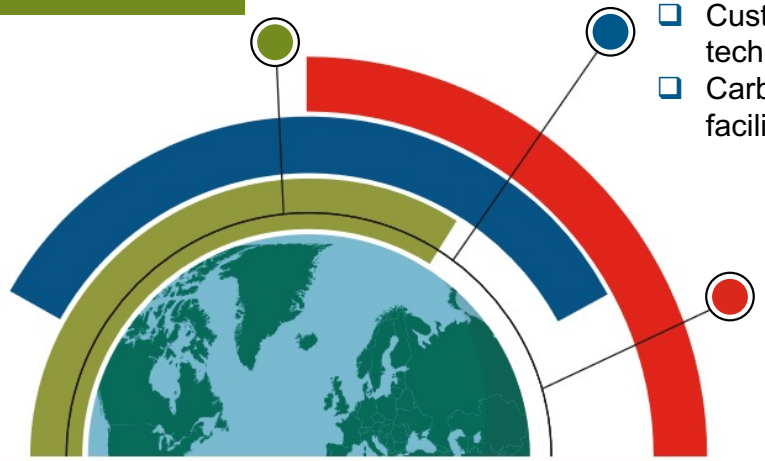
2050 Targets

- Net positive impact in every community in which we operate
  = sum of environmental good > local environment footprint
- Near zero local environmental impact

DOING OUR PART TO ADDRESS CLIMATE CHANGE AND AIR EMISSIONS

2050 Targets

- Customer success powered by carbon neutral technologies that address air quality
- Carbon neutrality and near zero pollution in Cummins' facilities and operations



USING NATURAL RESOURCES IN THE MOST SUSTAINABLE WAY

2050 Targets

- Nothing wasted
  - Design out waste in products and processes
  - Use materials again for next life
  - Reuse water and return clean to the community

NOTES *References to "facilities" relate to all consolidated operations and joint ventures subscribing to Cummins' Enterprise Environmental Management System. Goals will be periodically assessed for progress and continued practicability*

NEW POWER

Core Technologies

ELECTRIFIED POWER

Creating technologies and products for commercial battery electric vehicles

- On-highway: transit bus, school bus, medium-duty truck, walk-in van
- Off-highway: construction equipment, terminal tractor, material handling

FUEL CELLS

Creating and integrating components for hydrogen fuel cell electric vehicles and rail

- Electric vehicles: urban transit bus, commercial fleet, utility vehicle, electric lift truck
- Installation: freestanding electrical power plant

HYDROGEN GENERATION

Creating solutions for industrial and commercial hydrogen generation and MW-scale energy storage

- Industrial processes and fueling stations: PEM generator, alkaline hydrogen generator
- Critical and uninterruptible power supply, power-to-gas technology

CUMMINS NEW POWER APPLICATIONS

In the Field

BATTERY ELECTRIC

1. GILLIG battery electric transit bus
2. Blue Bird School Bus

FUEL CELLS

1. Scania Trucks
2. Alstom passenger train
3. Refuse Truck: Cummins fuel cells power FAUN electric refuse trucks on the road today in Europe

ELECTROLYZERS

1. Hybalance - 1.2-megawatt PEM electrolyzer
2. Cummins-Enbridge Power-to-Gas Facility
3. 5-megawatt PEM electrolzyer for Douglas Co Public Utilities District in Washington State (US)
4. HyLYZER 1000 – 20 MW PEM electrolyzer system
5. Uniper (power-to-gas)

HYDROGEN FUELING STATION

1. Hydrogen fueling station: Delivered electrolyzers for more than 50 hydrogen fueling stations

CUMMINS HYDROGEN TECHNOLOGY POWERS THE LARGEST PROTON EXCHANGE MEMBRANE (PEM) ELECTROLYZER IN OPERATION IN THE WORLD

- 20-megawatt PEM electrolyzer system to generate green hydrogen, the largest in operation in the world.
- The Cummins electrolyzer system is installed at the Air Liquide hydrogen production facility in Bécancour, Quebec.
- The Cummins PEM Electrolyzer can produce over 3,000 tons of hydrogen annually using clean hydropower.

Building Blocks of Hydrogen Policy

Design and execute national strategies

Reduce demand uncertainty

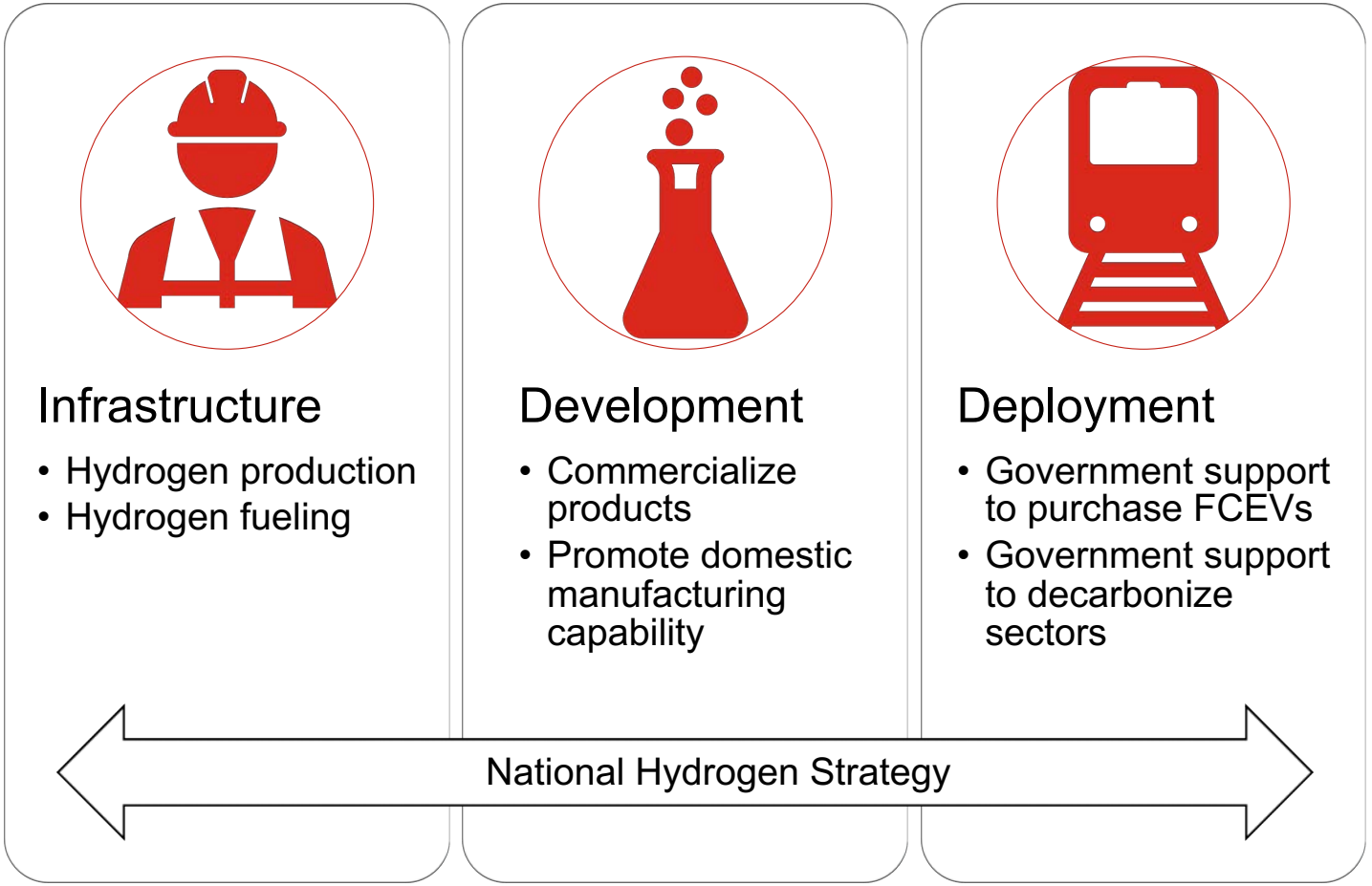
Invest in infrastructure

Continue research and development

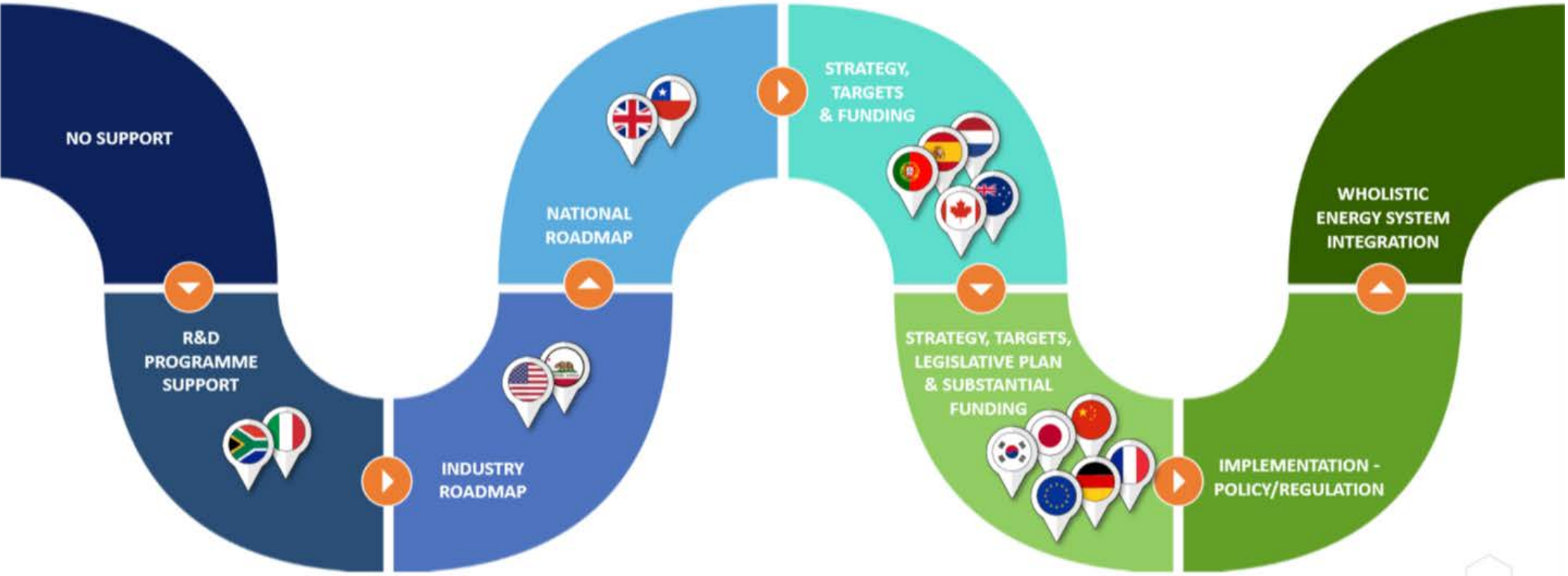
Accelerate deployment

Implement common definitions, codes and standards

How governments can promote adoption

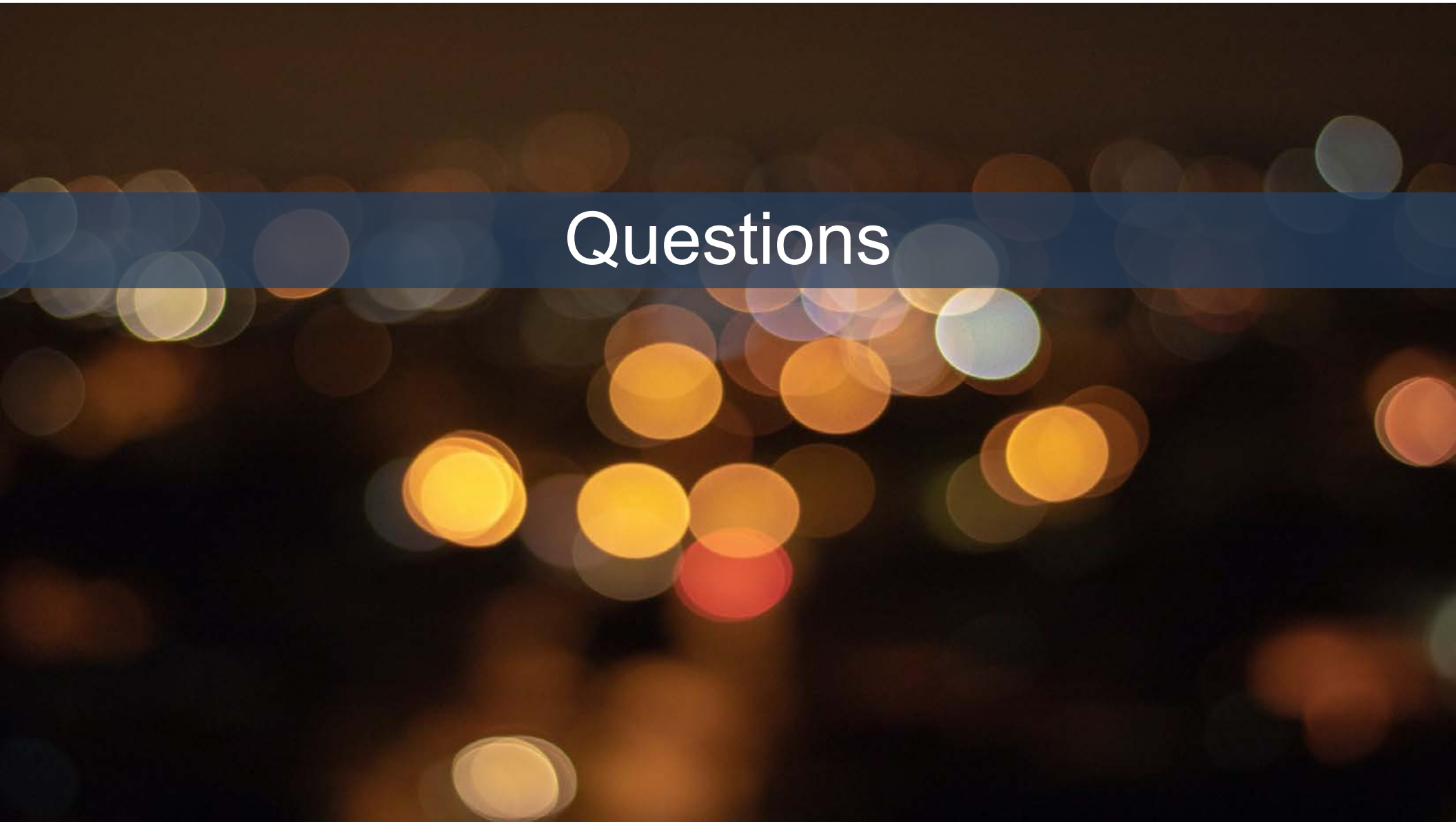


National Strategies




Cummins


Poll


Questions


Upcoming Event
The Future of
Hydrogen & RNG
in Canada
Part 4: Decarbonizing Heavy-Duty Vehicles in B.C.
June 30, 2021

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