



# **Powertrain Electrification and Fuel Cell R&D**

## **Power of Choice**

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H2@Scale End Use Applications for Truck

# Cummins Powers a Broad Range of Applications with Diverse Requirements

- The world's largest independent engine manufacturer
- Global manufacturing
- Broadest and most capable distribution and customer support network
- Powering more types of equipment in more markets than any other engine company



Common Requirements	
Fuel Efficient	Low Cost
High Power Density	Quick Start
Transient Operation	Durability

# CHANGING GROWTH DRIVERS



NEW TECHNOLOGIES

SUSTAINABILITY

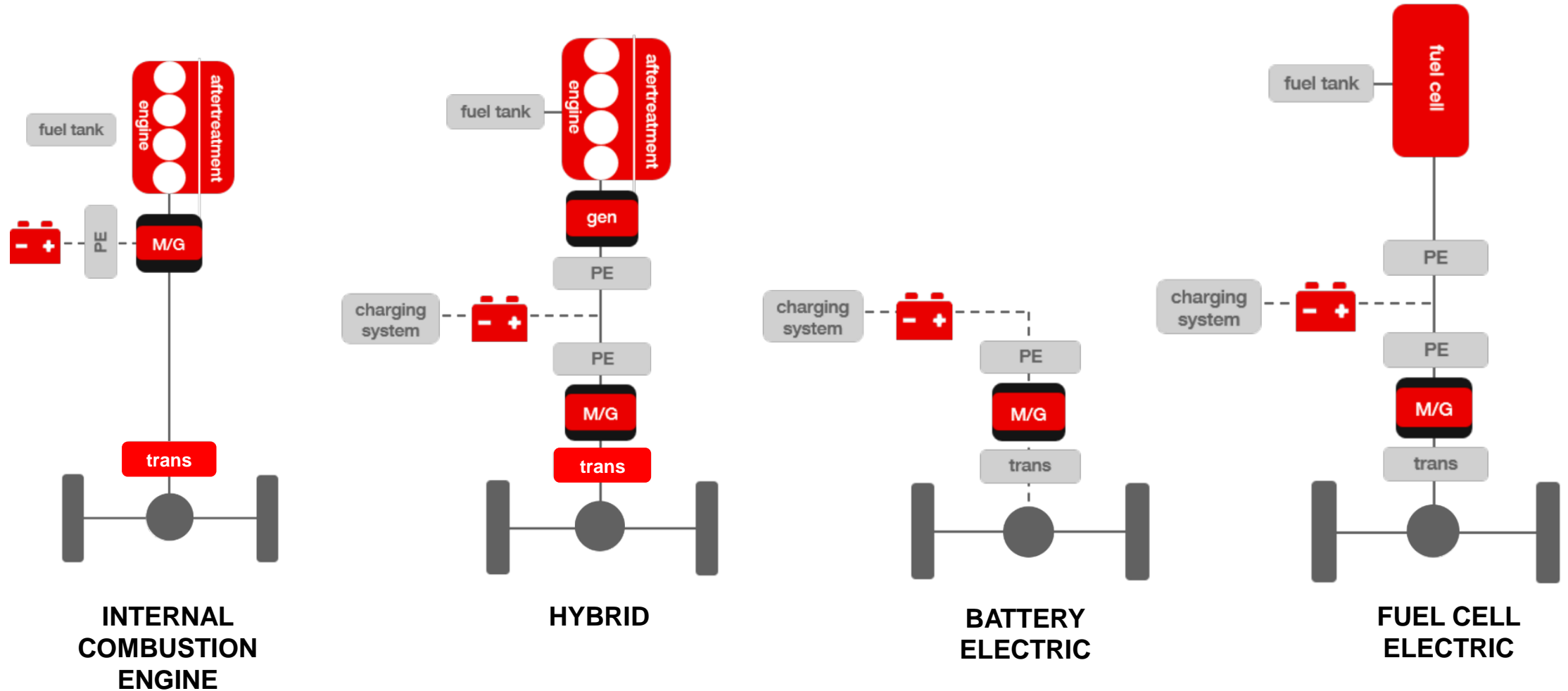
EMISSIONS REGULATIONS

ENERGY PRICES & AVAILABILITY

GLOBALIZATION

# Commercial Vehicle Applications

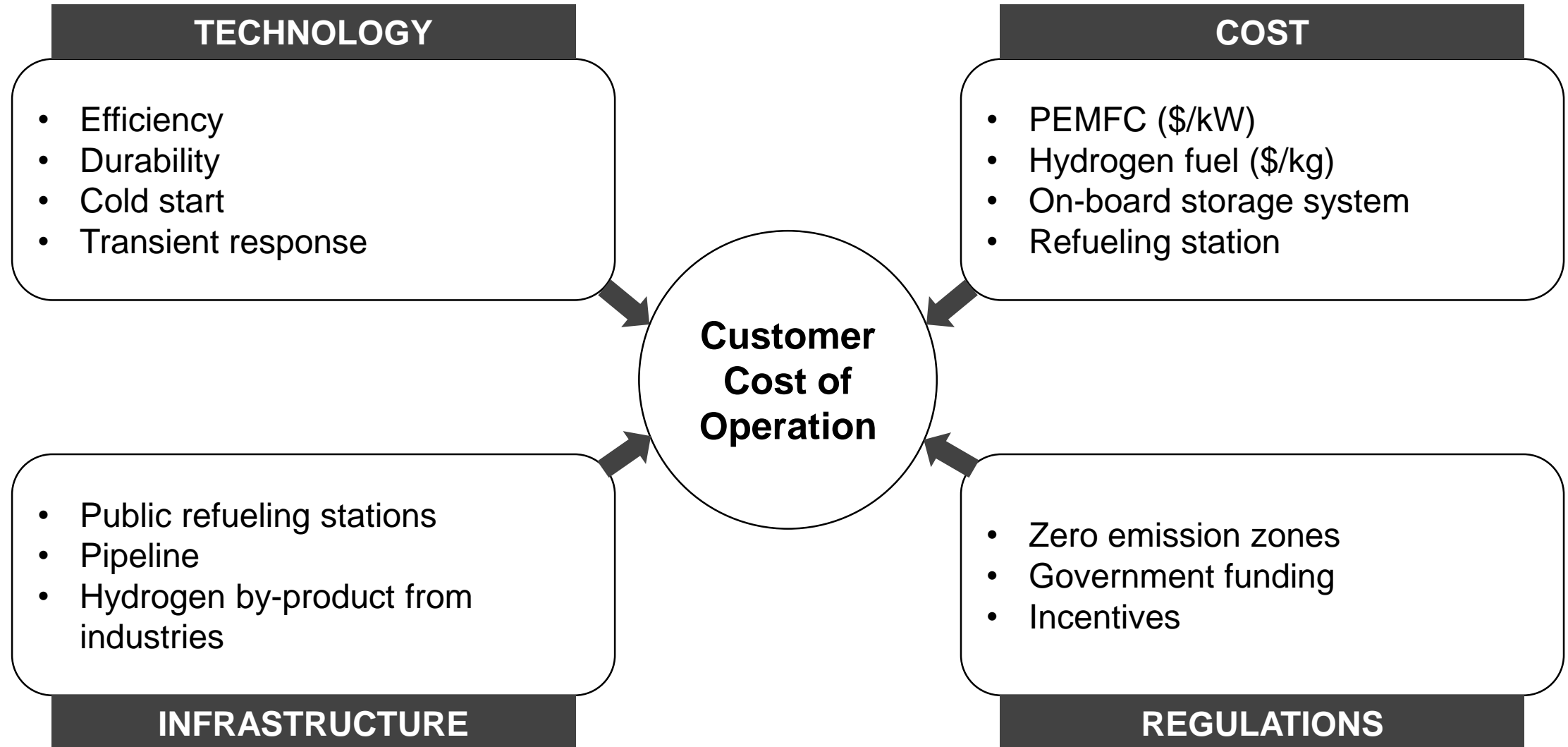
## “Powertrain of Choice”



# Benefits of PEM Fuel Cells

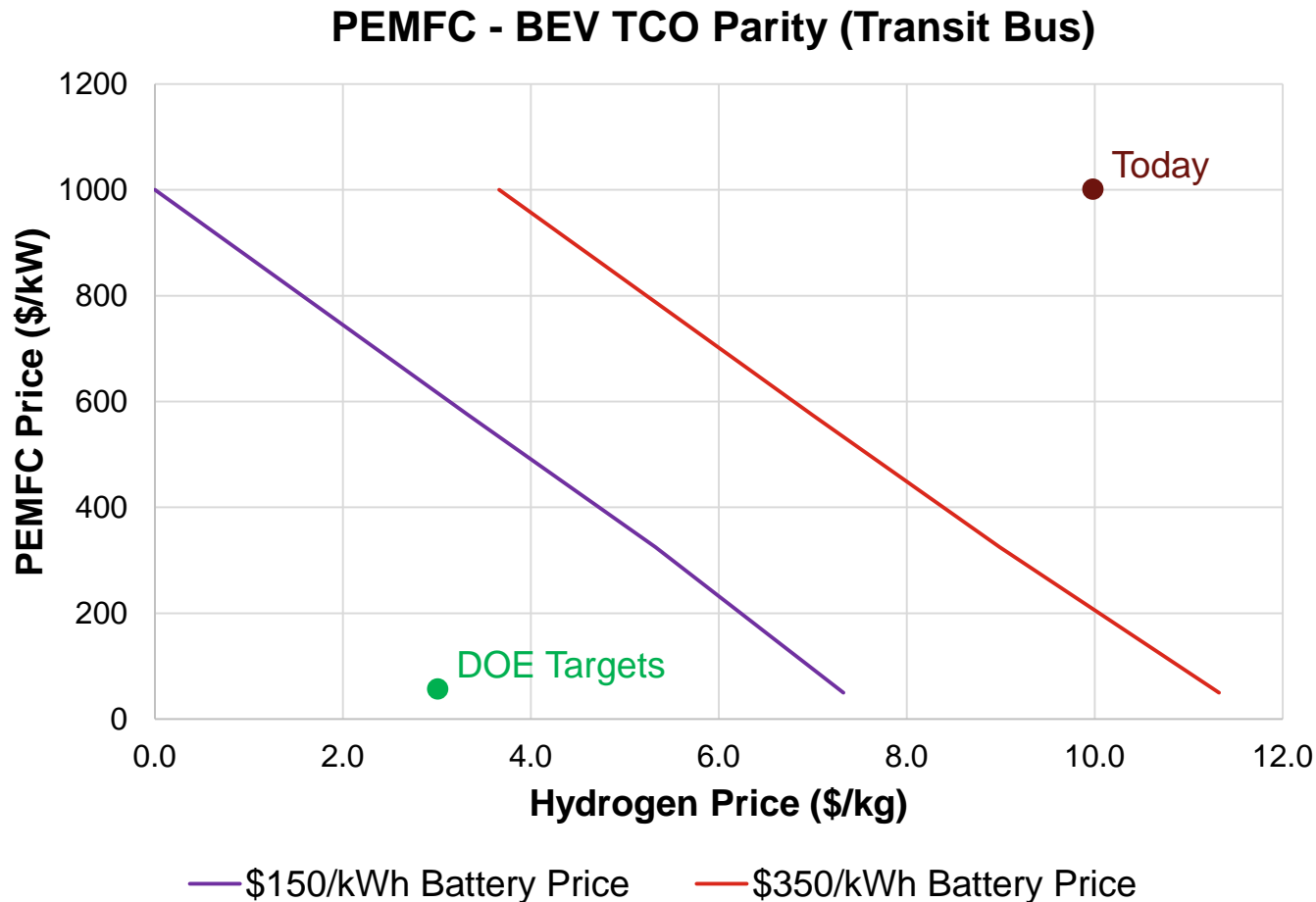
- Zero carbon, zero emissions (compared to conventional fuels)
- High energy density (compared to battery)
- Quick refueling (compared to battery)
- Improving performance & durability
- Immediate startup (compared to SOFC)
- Transient response (compared to SOFC)
- Improving cost of operation

# Key Drivers for Adoption of Technology



# Cost of Operation Model

## Transient Bus Example



- At today's price of hydrogen (~\$10/kg) and PEMFC system (\$1000/kW), total cost of operation (TCO) are not justified
- At DOE targets (\$50/kW and \$2-3 kg/H<sub>2</sub>), TCO could be better than EV

### Key elements in ecosystem

1. Electricity / Natural Gas price
2. Electrolysis / SMR equipment
3. H<sub>2</sub> & O<sub>2</sub> distribution
4. PEMFC system & on-board storage

# Building Capabilities Across the Value Chain

## CELLS & MATERIALS



Materials

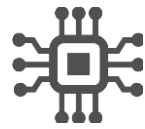


Cells

## MODULE COMPONENTS



Stack



Fuel cell controller



Air handling



Thermal management

## SYSTEM COMPONENTS



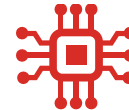
Fuel cell module



Battery pack



Motor generator

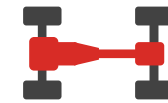


Controls



Power electronics

## SYSTEM INTEGRATION & AGGREGATION



Integrated powertrain system



On-board storage

