United Nations Framework Convention on Climate Change

Agenda item 4.c.ii

Enabling environment to enhance replicability and scalability of technologies for sustainable transport

Technology Executive Committee, 25th meeting and TEC-CTCN Joint session
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Technical paper on

Deep decarbonization technologies for sustainable road mobility

Prepared for the
United Nations Framework Convention on Climate Change (UNFCCC)

Technology Executive Committee (TEC)

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Context:

International Energy Agency's Net Zero Emissions scenario (NZE) summarizes the rapid transformations needed for **road transport**, including:

- 100% zero-emissions vehicle sales by 2035, mostly **electric vehicles** for light-duty vehicles
- Rapid advancement in **green hydrogen**, to fuel 30% of heavy-duty vehicles by 2050
- Rapid progress in **advanced biofuels** (low-carbon and sustainable)
- **Behaviour change**: 20-50% reduction in private vehicle use

Context:

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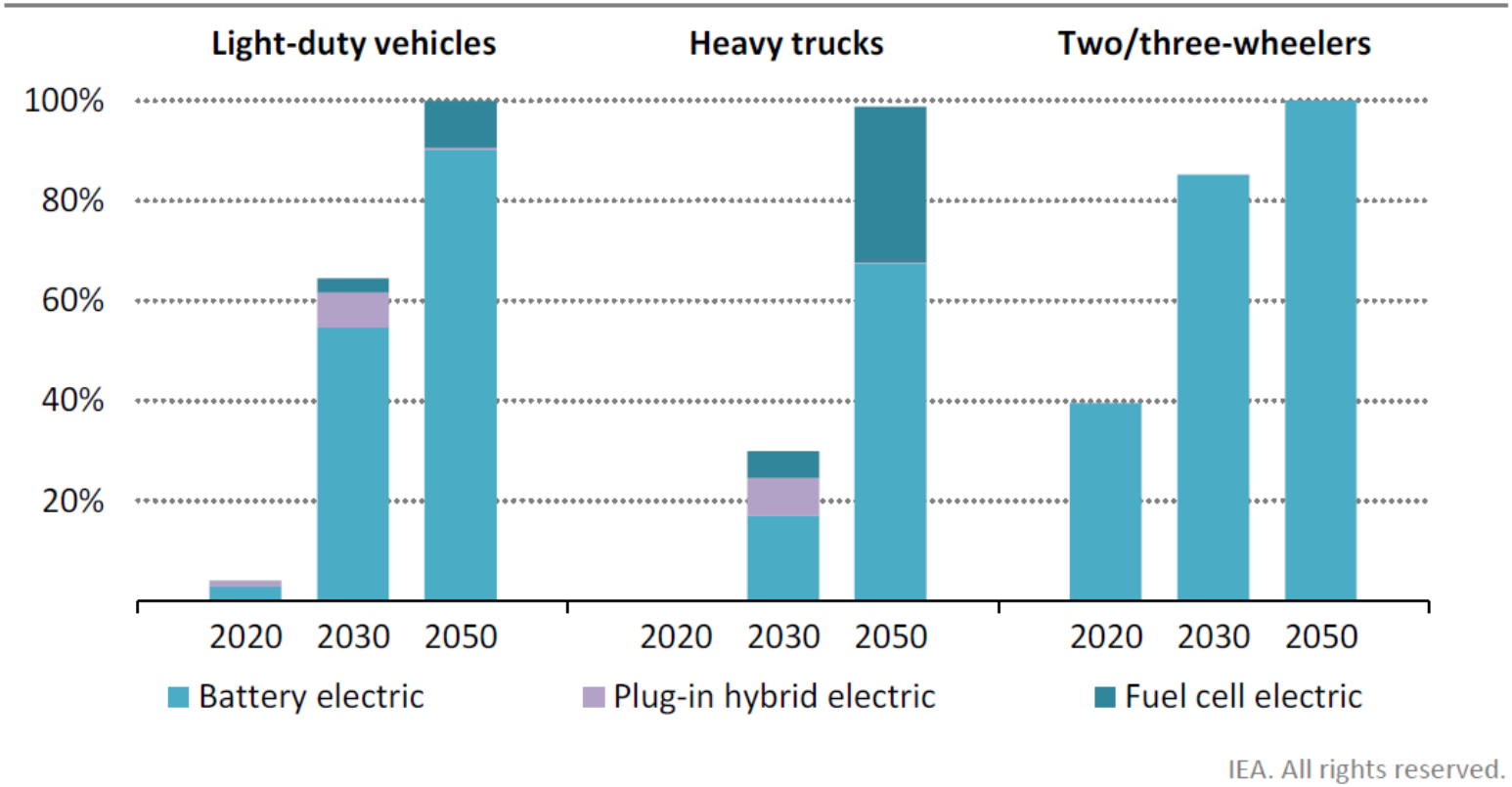

Sales of battery electric, plug-in hybrid and fuel cell electric vehicles soar globally

Research Objectives:

1. Provide an overview of the technologies and their **state of play**, including information on their **technology readiness** and potential **climate change mitigation** impacts;

2. Summarize **key barriers and opportunities** relating to social, institutional, economic and business aspects of their development and effective deployment; and

3. Identify and evaluate innovative **policy options**, opportunities and challenges for policymakers to effectively support the deployment of these technologies.

Method:
Technology Readiness Level (TRL) from NASA and IEA:

Broad stage	TRL	Narrow stage
Conceptual/research phase	1	Initial idea
	2	Application formulated
	3	Concept needs validation
Small prototype	4	Early prototype
Large prototype	5	Large prototype (validated in relevant environment)
	6	Full prototype at scale
Demonstration/Deployment	7	Pre-commercial demonstration
	8	First-of-a-kind commercial **(<0.1% sales)**
	9	Commercial operation in relevant environment **(0.1% to 1% sales)**
Early Adoption	10	Integration needed at scale **(1-10% sales)**
Mature	11	Proof of stability: predictable growth **(>10%)**

Methods:

Literature review (+220 references), including key documents from:

- International Energy Agency (IEA)
- International Council for Clean Transportation (ICCT)

GHG emissions, note differences between

- Tailpipe emissions: generally not used here
- **Well-to-wheel (WTW) emissions**: considers lifecycle impact of fuel production (electricity generation) and fuel usage.
- **Full lifecycle analysis (LCA):** considers WTW fuel emissions, plus manufacturing and disposal of vehicle

Results overview:

Technology	Sub-type	TRL	2021 penetration	Carbon impacts	Role in IEA NZE 2050 Scenario
Plug-in electric vehicle	Light-duty	10-11	Many countries: 1-15% Norway: 86%	NA/EU: 60-77% cuts China/India: 19-56% cuts	2030: 60% of global sales 2050: 90%
	Heavy-duty	8-11	Heavy trucks: ~0.1% Buses: 5-60%	34-98% cuts	2030: 17% of global sales 2050: 68%
Hydrogen fuel-cell vehicles	Light-duty	8	<0.1% sales	Grey H2: 26-40% cuts Green H2: 76-80% cuts	2050: ~10% of global sales
	Heavy-duty	8	<0.1% sales	Green H2: 65-97% cuts	2050: ~30% of global sales
Advanced biofuels	Ethanol	7-8	3% of gasoline, <0.1% is advanced	Up to 81% cuts	Advanced ethanol increases to 28% of ethanol by 2030
	Biodiesel	9	16% is advanced	85-92% cuts	Advanced biofuels meet 14% of transport energy by 2050
Shared mobility	Ride-hailing	9-11	~3% US adults are regular users	Unclear	"Behaviour" shift? 2050: 20-50% less private vehicle use
	Car-share	9-10	Over 30 million members globally	Unclear	"Behaviour" shift?
	Micromobility	9-10	Available in 650 cities	Unclear;.	"Behaviour" shift?
	Mobility as a Service	8	Very low, dozens of projects globally	Unclear;	"Behaviour" shift?
Fully automated vehicles	Light/heavy	4+	Demonstration only	Highly uncertain; halve or double GHG emissions;	Not addressed

Plug-in electric vehicles (PEVs):

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Barrier	Opportunities	Policies
1. High purchase costs	Lower cost PEVs, two/three-wheeler	Subsidies, ZEV mandate
2. Limited charging	Public-private partnerships, fast charging, battery swapping, catenary lines	Charger deployment; subsidies and regulation for installation
3. Grid impacts	Coordinate w/ renewables, smart charging, smaller PEVs (two/three-wheeler)	Time-of-use (TOU) pricing
4. Battery source materials	Expand domestic mining and manufacturing; increased R&D (e.g., cobalt-free)	Regulation for extraction and recycling
5. Consumer awareness and preferences	Marketing, demonstration, setting norms	ZEV mandate, information campaigns
6. Model availability/variety	Support new automakers; expand domestic auto industry	ZEV mandate
7. Fleet/commercial challenges	Marketing, demos, increase model variety	ZEV mandate, subsidies, info. campaigns for fleets
8. Equity impacts	Policy design for equity goals	Careful design of taxes and subsidies

Hydrogen fuel-cell vehicles (HFCVs)

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Barrier	Opportunities	Policies
1. High price	International alliances, R&D to bring down costs, focus on heavy-duty applications	Purchase/fuel subsidies, ZEV mandate
2. Very limited refueling	Public-private partnerships, R&D activity,	Subsidies, ZEV mandate
3. Limited green hydrogen generation	Expand renewable capacity, R&D activity, and subsidies	Subsidies, low-carbon fuel standards
4. Consumer awareness and preferences	Improved marketing and demonstration	ZEV mandate, info. campaigns, purchase incentives
5. Model availability/variety	Support FCEV automakers; expand FCEV industry	ZEV mandate
6. Competition from BEVs	Focus on long-haul heavy-duty applications	Match PEV policies for FCEVs

Advanced biofuels

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Barrier	Opportunities	Policies
1. Impacts to food prices and security	Focus on non-food crops, develop partnerships to plan land use	Include food/land considerations in low-carbon fuel standard (LCFS) policy
2. High carbon sources	Invest in "advanced" biofuels, carbon capture & storage	LCFS, link subsidies to low carbon content
3. High price	R&D in advanced feedstocks (e.g., switchgrass, wheat straw, HDRD), develop low-cost resources in developing countries	Subsidies, LCFS
4. Limited refueling	Public-private partnerships	Refueling deployment, LCFS
5. Lack of compatible vehicles	Develop "drop-in" fuels (e.g., HDRD)	ZEV mandate, information campaigns

Shared mobility

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Barrier	Opportunities	Policies
1. Consumer preference	Improve consumer research, improved service, education, marketing, demonstration, integration with public transit (MaaS)	Carbon/road price, incentives for usage (pooling)
2. Increasing VKM	Support pooling, integration with public transit (MaaS)	Carbon/road price, tolls for single occupancy vehicles
3. Uncertain GHG impacts	Integrate with national/regional GHG plans, pair with PEV deployment	Carbon/road price, ZEV mandate (for car-share, ride-hailing)

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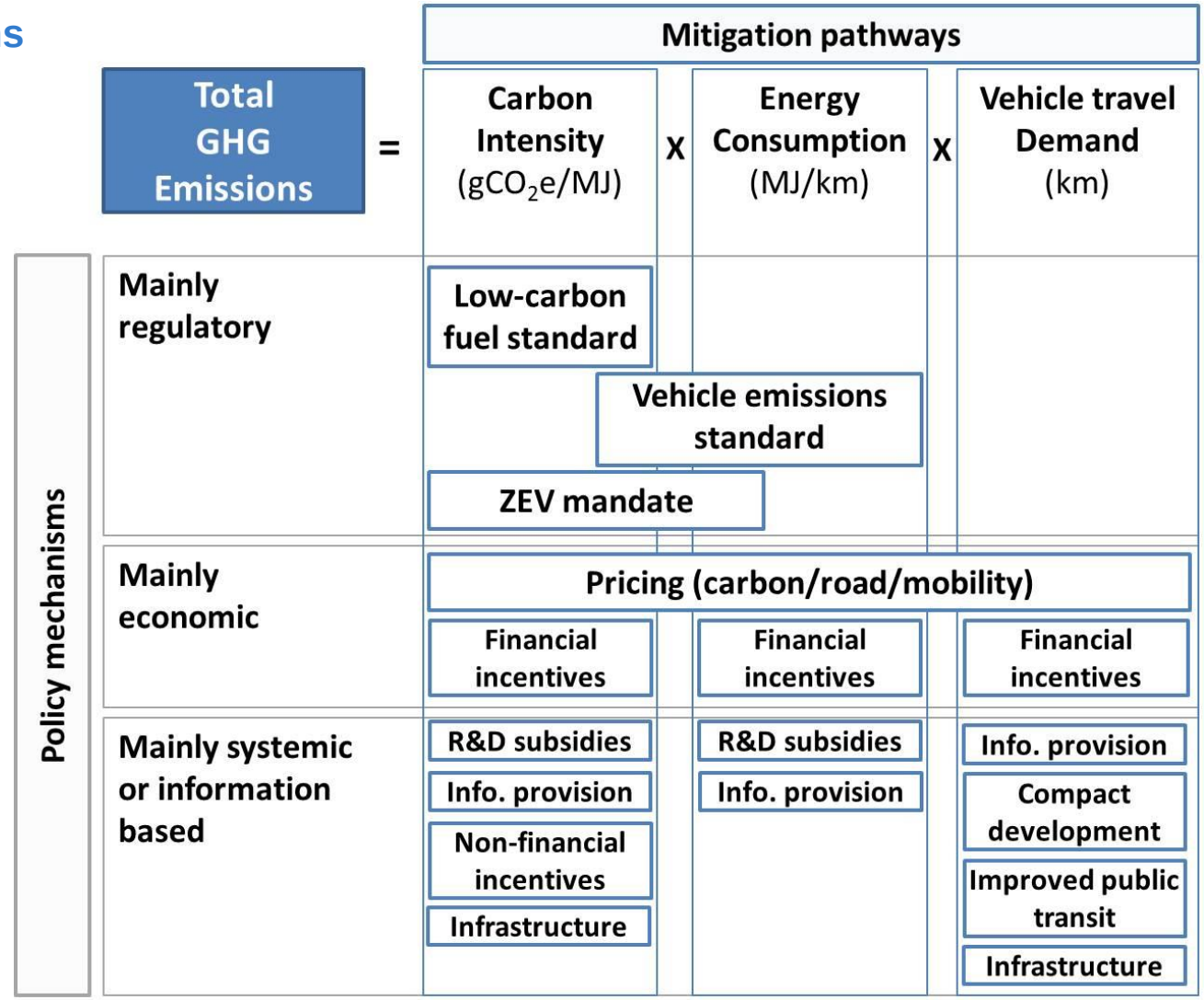
Barrier	Opportunities	Policies
1. Consumer confusion/preference	Education, demonstration, participatory engagement	R&D support
2. Lack of sharing	Consumer engagement, demonstrations	Carbon or road pricing, reduced parking
3. Increasing VKM		Carbon or road pricing, urban planning
4. Developing country challenges (costs and infrastructure)	Expand tech R&D in developing countries, explore sharing scenarios	R&D support

Policy Options



Climate policies

Policy	Strengths	Challenges
Pricing	Effective, efficient, comprehensive	Political opposition
Market-oriented regulations	**ZEV sales mandate:** Transformative signal (channels R&D), boosts ZEV sales (cross-price subsidies) **Vehicle emissions standard:** can act as ZEV mandate **Low-carbon fuel standard (LCFS):** pushes transformation in low-carbon fuels **All:** acceptable to public	Complex, opposition from incumbent industry, how efficient?
Incentives	Effective (boost sales), political acceptable	Costly
Chargers deployment	Addresses crucial barrier, politically acceptable, can help with norms	Not sufficient alone (needs mix)
R&D subsidies	Can help with transformation	Impacts unclear

Key findings

- Highest technology-readiness (TRL) for plug-in electric light-duty vehicles and buses
- Lower readiness for:
  - Heavy-duty trucks (notably long-haul)
  - Fuel-cell hydrogen vehicles
  - Advanced biofuels (ethanol and biodiesel)
- More research and policy for ZEV manufacturing and disposal
- Shared mobility and automation have unclear roles in decarbonization, though climate policy can induce more climate benefits

Potential actions for policymakers

- Plan out complementary policy mix for regional context
- Focus on ZEV sales mandate
- Use low-carbon fuel standard for upstream emissions
- Pricing as complement (if acceptable)
- ZEV purchase incentives help, more short-term
- Charger deployment and R&D support can help
- Improve institutional capacity

Thank you!