Hydrogen Fuel for Transport in India

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Why Hydrogen as A Transport Fuel?

Climate and environmental benefits

- No tailpipe emissions

Flexibility in fuel transmission

- Can be transported in either gaseous or liquid form via pipeline or truck

Flexibility in production pathway

- Could deploy different feedstocks and technologies in producing hydrogen

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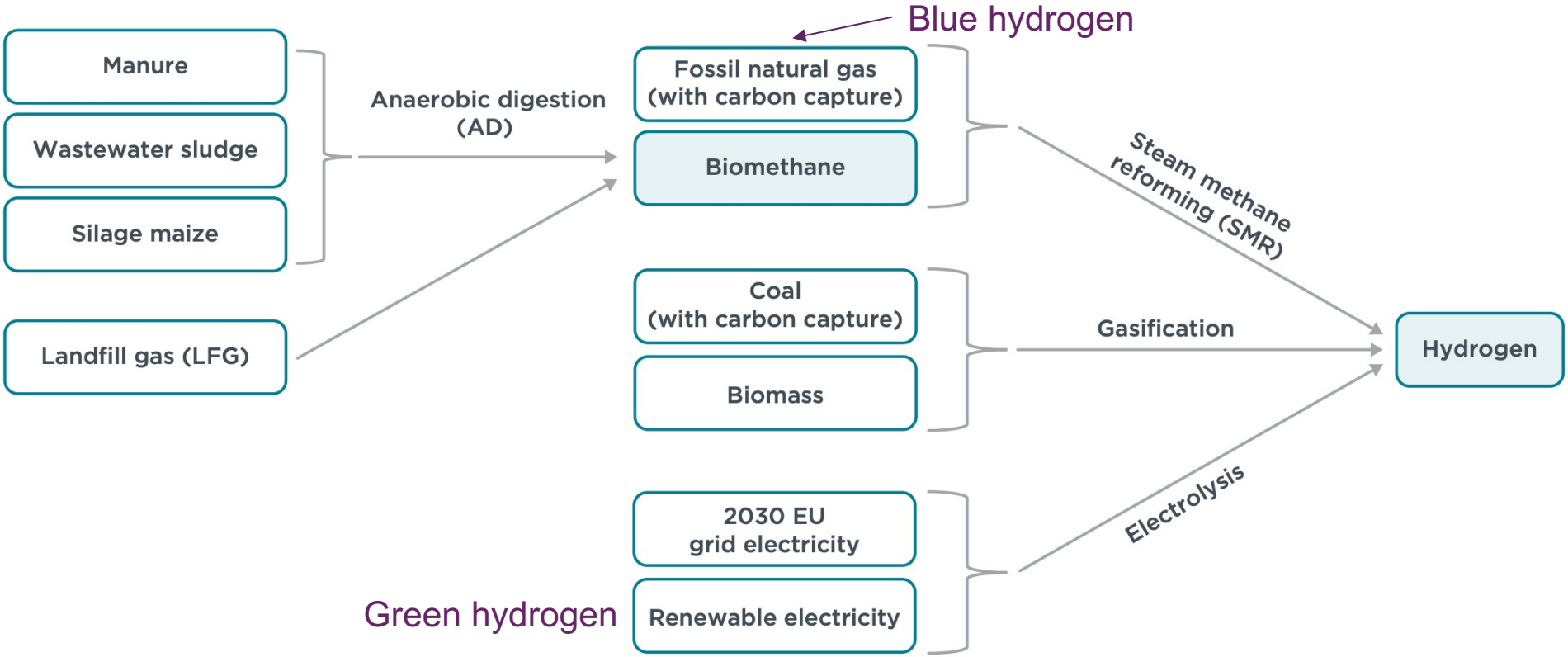
Hydrogen Production Pathways



Hydrogen in India

Align with India's emission reduction goals

- Net-zero by 2070 while transport being the third most emitting sector
- Stringent tailpipe air pollutant emission standard
- Hydrogen use in transport is limited to hythane - controversy on tailpipe emissions

Align with India's energy independence goal

- Government target of 10% reduction in oil & gas imports by 2022 relative to 2014-15 levels

Substantial renewable resources in India

- Significant efforts in scaling up solar electricity
- Plans to scale up green hydrogen: The National Hydrogen Mission in 2021

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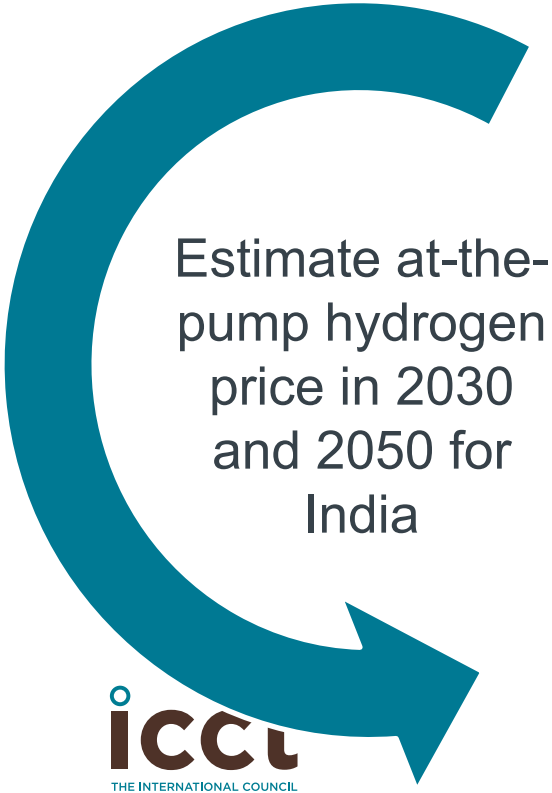
Study Objective and Scope



Three case studies: Ahmedabad, Mumbai, New Delhi

Production
- Blue hydrogen (natural gas + CCS)
- Green hydrogen (solar electricity)

Transport
- Pipeline transmission and distribution

Fueling Station
- Cost of building and operating hydrogen fueling stations

Tariff
- Taxes collected along hydrogen supply chain

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Green Hydrogen Production Cost

- Adopt a cashflow model to project levelized production cost per kg hydrogen
- Collect past solar price in India and current electrolysis cost
- Project future green hydrogen production cost
  - Optimistic decrease in solar price
  - Mid-level and optimistic improvements in electrolysis

Location	Ahmedabad		Mumbai		New Delhi	
Baseline price of solar electricity	$0.035/kWh		$0.042/kWh		$0.040/kWh	
Projected price of solar electricity	2030	2050	2030	2050	2030	2050
	$0.022/kWh	$0.015/kWh	$0.027/kWh	$0.018/kWh	$0.026/kWh	$0.017/kWh
Solar and electrolyzer capacity factor	20%		20%		20%	

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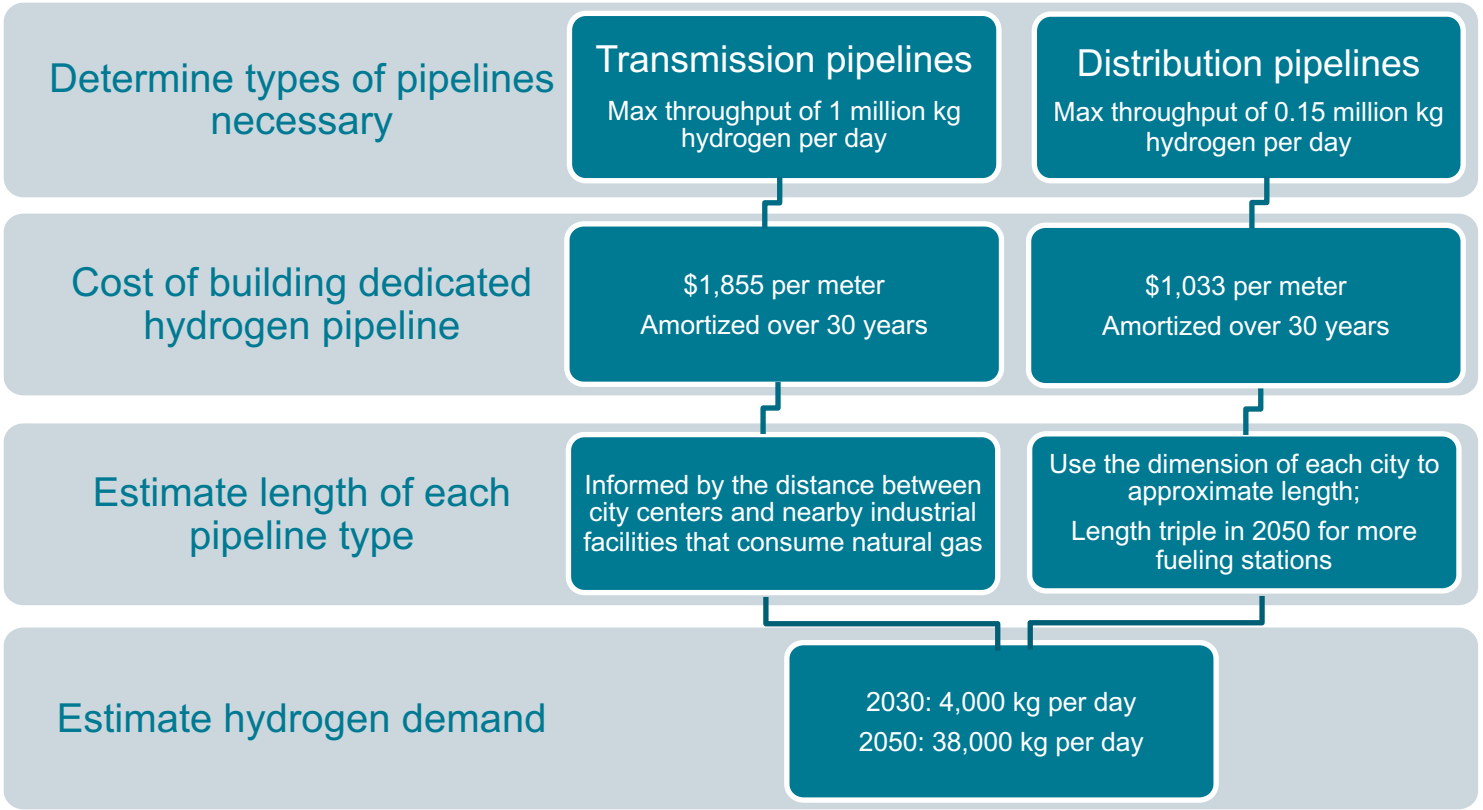
Blue Hydrogen Production Cost

- Collect current cost in steam methane reforming (SMR) and carbon capture and storage (CCS) and assume constant for the future
- Project future blue hydrogen production cost: increasing natural gas price

	Ahmedabad	Mumbai	New Delhi
Wholesale natural gas price	2030: US$6.5/MMBtu (INR 460/MMBtu) 2050: US$6.9/MMBtu (INR 490/MMBtu)		
Natural gas value added tax	6%	3%	5%
Transmission pipeline tariff plus tax	US$0.85/MMBtu (INR 59.68/MMBtu)		
Retail natural gas price	2030: US$7.8/MMBtu (INR 547/MMBtu)	2030: US$7.6/MMBtu (INR 533/MMBtu)	2030: US$7.7/MMBtu (INR 542/MMBtu)
	2050: US$8.2/MMBtu (INR 577/MMBtu)	2050: US$8/MMBtu (INR 562/MMBtu)	2050: US$8.1/MMBtu (INR 572/MMBtu)

Hydrogen Pipeline Transport Cost



Fueling Station Cost

<table>
<tr><th>Parameter</th><th colspan="4">Value</th></tr>
<tr><td rowspan="3">Number of hydrogen fueling stations and station capacity in each city</td><td colspan="2">2030</td><td colspan="2">2050</td></tr>
<tr><td rowspan="2">10 stations</td><td rowspan="2">Fueling capacity of each station: 400 kg hydrogen per day</td><td>20 stations</td><td>Capacity: 400 kg H_2 per day</td></tr>
<tr><td>30 stations</td><td>Capacity: 1,000 kg H_2 per day</td></tr>
<tr><td>Daily hydrogen demand</td><td colspan="2">4,000 kg</td><td colspan="2">38,000 kg</td></tr>
</table>

- Collect fueling station construction and maintenance costs
- Calculate the levelized per kg cost using assumed hydrogen demand
- Add hydrogen purification cost

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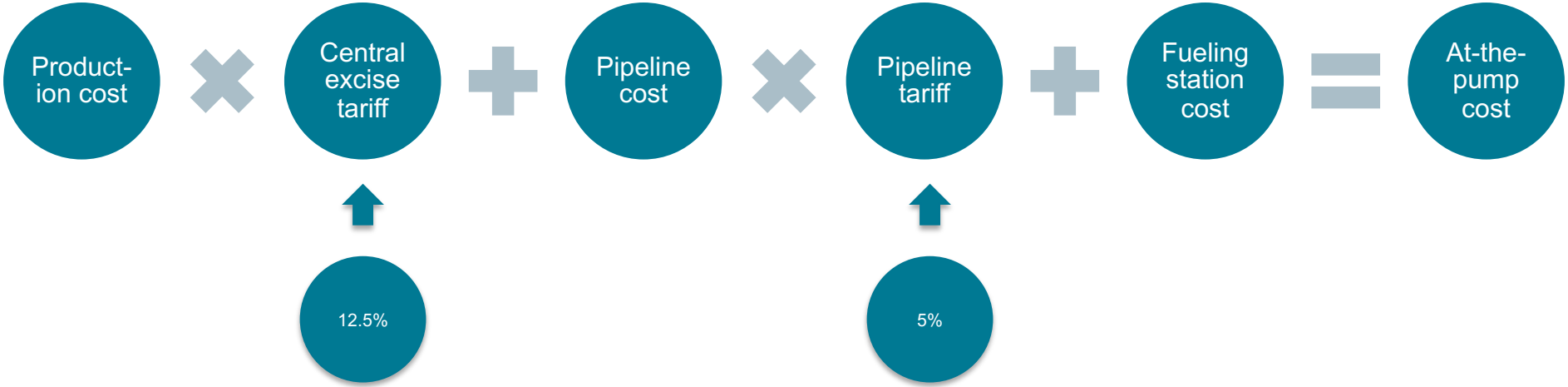
At-the-Pump Cost Calculation



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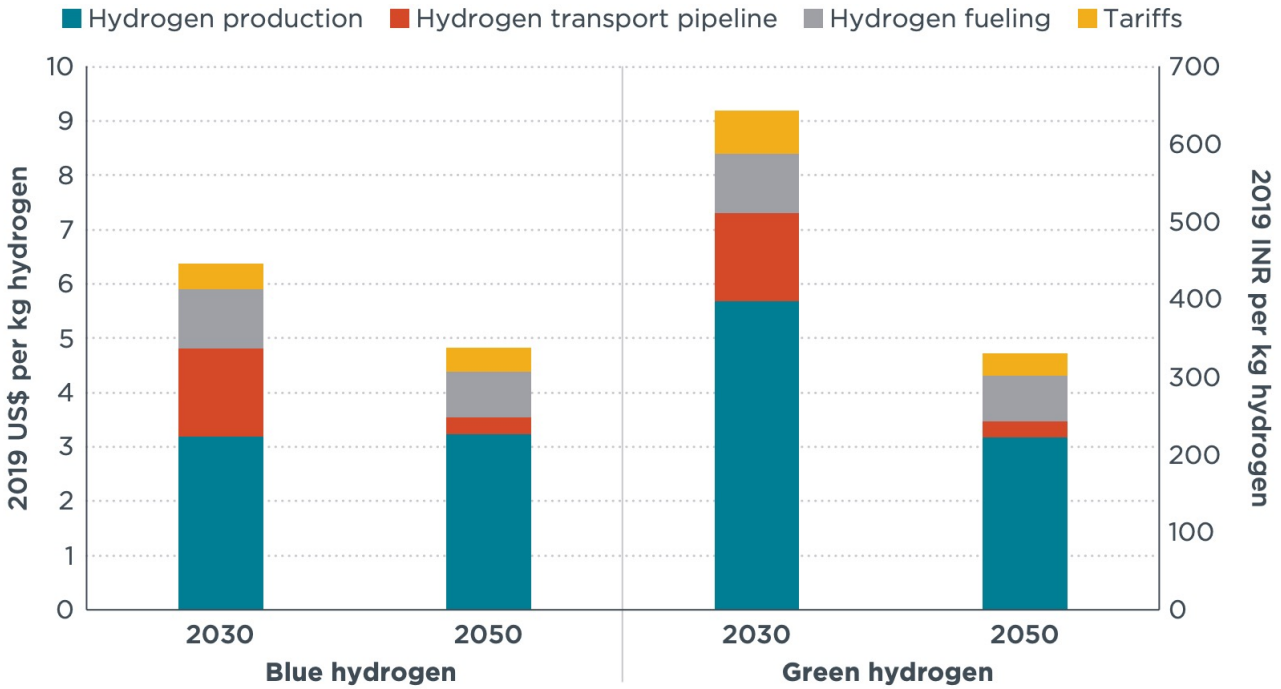
Results – Cost Breakdown



Breakdown of at-the-pump hydrogen costs averaged across all three cities: Mumbai, Ahmedabad, and New Delhi. Mid-level green hydrogen outlook.

Key takeaways:

- Green hydrogen is economically better in the long term
- Hydrogen production cost is the key to reach the fuel's cost competitiveness
- Economies of scale can drive hydrogen transport cost down

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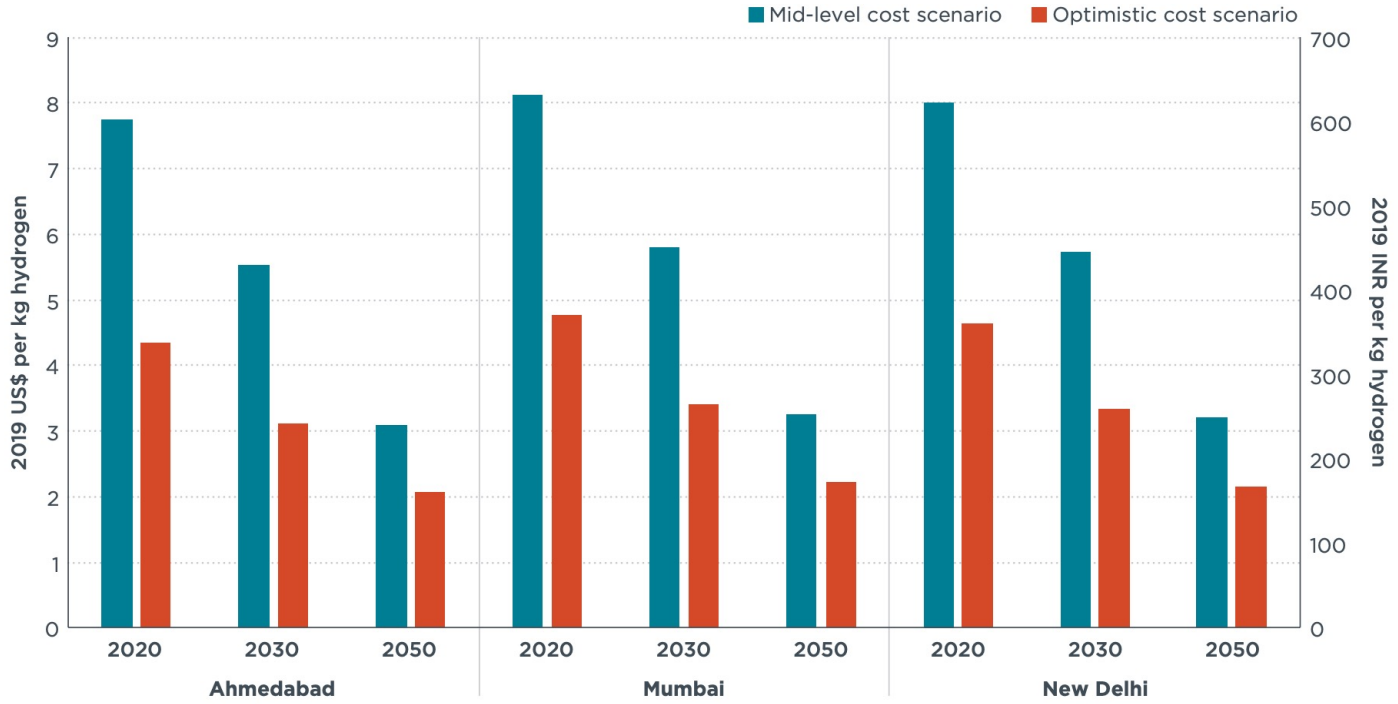
Results
– How Cheap Can Green Hydrogen Reach

An optimistic outlook can lower green hydrogen production cost by 40%



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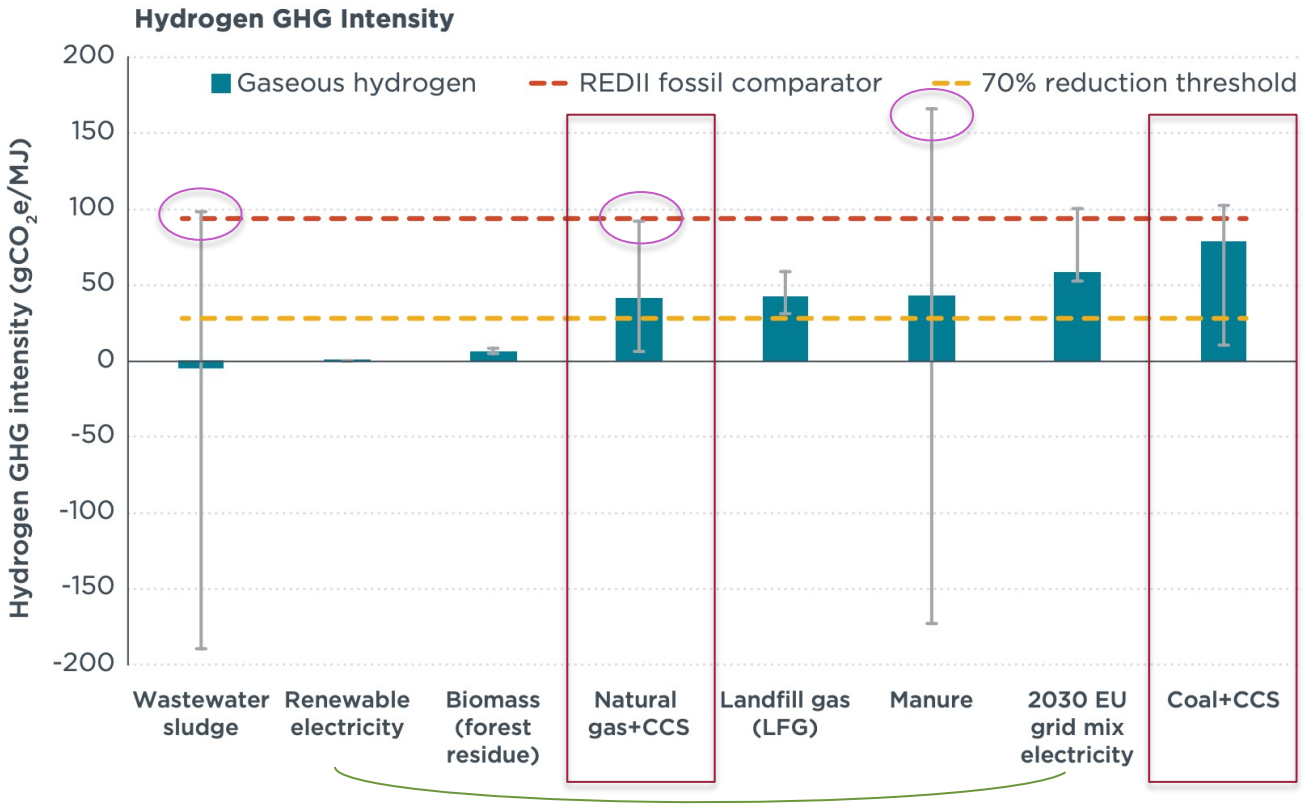
Comparison with Previous Studies

	IGIDR	TERI		This study	
Year of cost estimate	**2007**	**2030**	**2050**	**2030**	**2050**
Natural gas price per MMBtu	3.1 (220)	11.6 (815)	12.6 (890)	7.7 (540)	8.1 (570)
Natural gas-based hydrogen production cost	1.6 (115)	2.3 (160)	2.1 (150)	3.2 (225)	3.3 (230)
Electricity price per kWh	0.11 (8)	0.023 (1.6)	0.018 (1.3)	0.025 (1.8)	0.017 (1.2)
Electrolysis hydrogen production cost	9.1 (640)	2.1 (150)	1.1 (80)	5.7 (400) mid-level	3.2 (224) mid-level
				4.6 (325) optimistic	2.2 (150) optimistic
Pipeline transport cost	0.9 (70)	0.12 (8)	0.1 (7)	1.6 (115)	0.3 (20)
Fueling Infrastructure cost	1.2 (85)	—	—	1.1 (76)	0.8 (60)
Natural gas-based hydrogen at the pump price	3.8 (265)	4 (280)	2.2 (154)	6.4 (450)	4.8 (340)
Electrolysis hydrogen at-the-pump price	11.3 (795)			9.2 (650)	4.7 (335)

Note: All costs are expressed in 2019 U.S. dollars per kg hydrogen and the INR per kg hydrogen costs are in the parentheses. Results from IGIDR (2007) are inflation adjusted. IGIDR's hydrogen pathways differ from TERI's and ICCT's in that natural gas-based hydrogen is not combined with CCS and electrolysis hydrogen is made from grid electricity.

Sources: Indira Gandhi Institute of Development Research, 2007, http://www.igidr.ac.in/pdf/publication/WP-2007-004.pdf
TERI, 2020, https://www.teriin.org/sites/default/files/2020-12/Report%20on%20The%20Potential%20Role%20of%20Hydrogen%20in%20India%20%E2%80%93%20%27Harnessing%20the%20Hype%27.pdf

Hydrogen Lifecycle GHG Intensity



Key takeaways:

- High risk from fossil-based hydrogen
- Huge uncertainty in methane leakage rate and high leakage can make certain pathways worse than fossil fuel
- Electrolysis hydrogen using grid has much higher emissions than using renewable electricity

Source: Zhou et al, 2021
https://theicct.org/publication/life-cycle-greenhouse-gas-emissions-of-biomethane-and-hydrogen-pathways-in-the-european-union/

Conclusions

Green hydrogen is the sustainable, long-term solution that delivers the greatest climate and energy security benefits in India

Policy support in green hydrogen production is the key to reach cost competitiveness

Hydrogen infrastructure can benefit from greater capacity utilization and economies of scale driven by increased demand

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Questions?

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City Wise Cost Breakdown

2019 U.S. dollars per kg hydrogen (2019 INR per kg hydrogen)	Ahmedabad		Mumbai		New Delhi	
Target year	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Blue hydrogen production cost	3.21 (226)	3.27 (230)	3.18 (224)	3.24 (228)	3.2 (225)	3.26 (230)
Green hydrogen production cost_mid-level outlook	5.52 (390)	3.1 (220)	5.8 (410)	3.25 (230)	5.73 (400)	3.2 (225)
Green hydrogen production cost_ optimistic outlook	3.11 (220)	2.06 (145)	3.41 (240)	2.22 (156)	3.34 (235)	2.16 (152)
Pipeline transport cost	1.7 (120)	0.28 (20)	2.02 (142)	0.34 (25)	1.19 (85)	0.25 (18)
Hydrogen fueling cost	1.08 (76)	0.85 (60)	1.08 (76)	0.85 (60)	1.08 (76)	0.85 (60)
Blue hydrogen at-the-pump price	6.47 (455)	4.82 (340)	6.77 (480)	4.85 (340)	5.92 (420)	4.77 (335)
Green hydrogen at-the-pump price_ mid-level outlook	9.07 (640)	4.63 (325)	9.72 (685)	4.86 (340)	8.77 (620)	4.71 (330)
Green hydrogen at-the-pump price_ optimistic outlook	6.36 (450)	3.46 (245)	7.03 (495)	3.7 (260)	6.08 (430)	3.54 (250)