Forecasting a Realistic Electricity Infrastructure Buildout for Medium- & Heavy-Duty Battery Electric Vehicles

EXECUTIVE SUMMARY

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Executive Summary: key findings (1/2)

1. To electrify all U.S. medium and heavy-duty vehicles, fleets and charge point operators will need to invest **USD 620 billion into charging infrastructure - which includes chargers, site infrastructure, and utility service costs**

2. **Local MDHD vehicles** would need investment into **on-site charging infrastructure of USD 496 B**, but heavy-duty vehicles will require more significant charging infrastructure and investment compared to medium-duty – **requiring average charging infrastructure investment of 145K per vehicle for heavy duty vs 54K per vehicle for medium-duty**

3. **In addition to on-site** charging infrastructure, **high mileage vehicles** (most of which are Class 7 and 8) **require an investment of USD 69 bn into a reliable local on-route charging network** before they can electrify, but utilization risk poses a major challenge to investment – requiring significant government intervention and business model innovation

4. **To support** full electrification of **long-haul vehicles, USD 57 bn need to be invested** into the development of a sufficiently **dense highway-charging network** – development is constrained by the pace of transmission grid infrastructure buildout

5. Nationally, **just to support local charging demand[2)]** from MDHD vehicles, **utilities would need to invest around USD 370 billion[1)] on distribution grid upgrades and new builds**, which is nearly equivalent what was invested into the entire distribution grid over the past 15 years

6. In terms of **electricity generation and transmission**, while there will be some incremental capacity need (and investment need) created by MDHD charging, **power system operators are already planning for significant generation and capacity growth**, which exceeds projected demand from MDHD charging by a factor of ~10x

1) Based on "overnight" capital cost of grid infrastructure at current price levels - actual utility investment will be higher due to 1) price inflation of labor and equipment, and 2) Utility guaranteed rate of return
2) Distribution grids will serve on-site and on-route charging demand from local fleets - long-haul trucks / highway charging stations will be served by the transmission grid and bulk power system

Executive Summary: implications and key takeaways (2/2)

1. A **phased electrification approach** is clearly needed for MDHD vehicles, with an **initial focus on medium-duty** segment, and with **heavy-duty and long-haul addressed over time** as technology and infrastructure improve

2. **Given the significant** (and in some cases, prohibitive) **investments required for electrification**, there may be greater **value in being open to alternative decarbonization routes**, as opposed to being prescriptive on technology

3. Meeting ambitious electrification and decarbonization targets **may require fleets to explore and innovate alternative operational and fleet management strategies** to optimize upfront investments and long-term value

4. **Without sufficient government and regulatory support**, the transition to fully electric MDHD fleets would **likely result in increased freight rates**, costs that would have to ultimately be passed down to American consumers

5. If faced with completely **"unmanaged" charging demand, distribution grids will require extensive infrastructure investment**, creating a bottleneck for fleet electrification given the need to maintain affordable rates – this **highlights the need for technology solutions and regulatory support** to help fleets and utilities **manage charging**

6. Overall, **these findings clearly highlight the need for greater cross-industry collaboration** to increase alignment and certainty for all stakeholders

To electrify all MDHD vehicles, fleets and charge point operators will need to invest USD 620 billion into chargers, site infrastructure, and utility service costs

Charging infrastructure investment needs

Vehicle cost/TCO not in scope of analysis

Use case segment	Vehicle
1 Medium duty – local (low mileage)	• Vehicles expected to meet performance requirements of all use cases in improved technology scenario • Vehicle prices are assumed to decline to enable positive TCO across use cases
2 Medium duty – local (high mileage)	
3 Heavy duty – local	
4 Heavy duty – long haul	

Charging infrastructure

Charger	Site	Electric service	
Local charging networks			**565 B**
A	L2 on-site		163 B
A	L3 on-site		333 B
B	500 kW on-route		69 B
Highway charging networks			**57 B**
C	L3 on-route		30 B
C	1 MW on-route		27 B

Total on-site charging investment needed
496 B

Total on-route charging investment needed
126 B

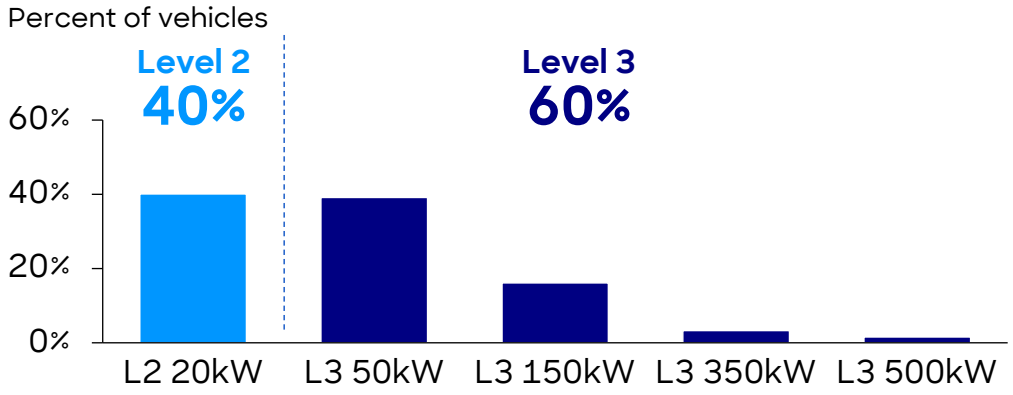
Compared to medium-duty, heavy-duty vehicles will require more significant charging infrastructure and investment due to more intensive charging needs

Investment need for local on-site charging network

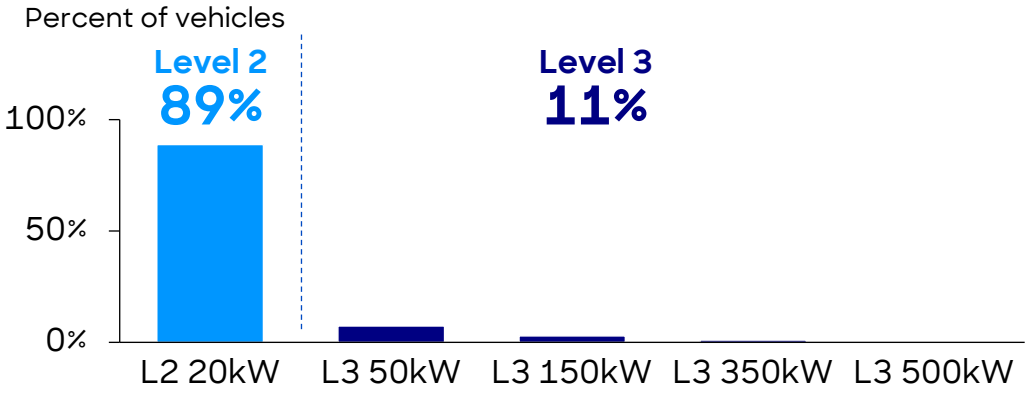
Segment

Required on-site charger technology

Heavy duty - local



Medium duty - local



Total investment need local on-site charging network [USD]

L2 on-site	L3 on-site
163 B	333 B
22 B HD	220 B
141 B MD	113 B

Charging infrastructure investment per vehicle [USD]

Heavy duty - local

145 K

Medium duty - local

54 K

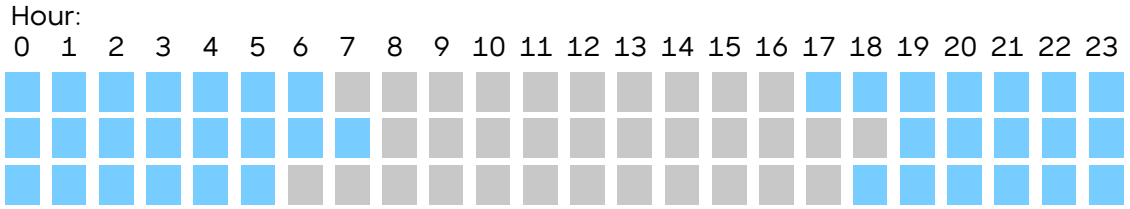
Heavy duty vehicles have more intensive charging requirements, and will require ~3X the infrastructure investment per vehicle compared to medium duty

Source: NREL; US Census Bureau, Roland Berger analysis

Low mileage medium-duty vehicles will not need on-route charging, and can use Level 2 chargers on-site, minimizing charger and make-ready investments…

Illustrative charging and utility service need for MD local fleet (low mileage)

I Illustrative duty cycle for Class 6 delivery fleet



Available charging time at home base typically >12 hours

II Illustrative on-site charging need

x 30	131 kWh	13	20 kW L2 x 30	→	**600 kW**
fleet size	effective full charge	avg. hours overnight	on-site chargers needed		incremental service need

III Indicative cost of utility service upgrades

Minor utility service upgrades can cost in the range of

USD 7,500 per L2 charger

for typical fleet locations

Cost of utility service upgrade (paid by fleet)

USD 225K total

USD ~7,500 per vehicle

at home base on-duty

However, for depot locations with a larger number of vehicles, a more extensive service upgrade may be needed …

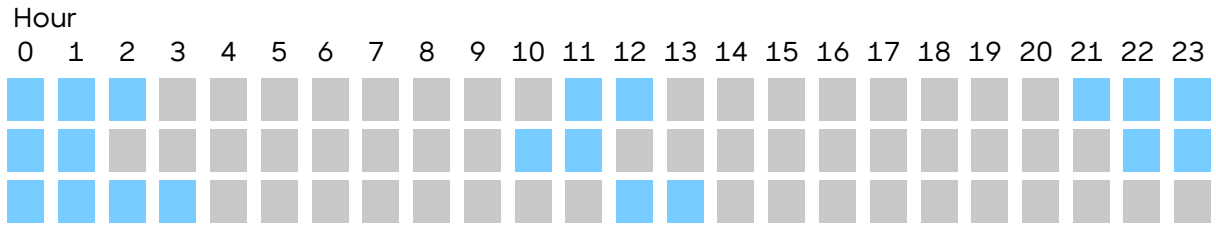
- This same example fleet, if it consisted of 150 vehicles instead of 30, would require a **3 MW service level**
- For individual sites requiring significant power capacity (~ 1 MW and above), **utilities may need to upgrade more upstream infrastructure** (e.g. feeder segments, larger transformers), which can translate into much larger investment need on a per vehicle basis
- These costs are highly variable, depending on existing infrastructure

Source: NREL; Roland Berger analysis

… but for many local HD use cases, fleets would need high capacity L3 or DCFC chargers on-site, but just the cost of utility service upgrades can be prohibitive

Illustrative charging and utility service need for HD local fleet

I Illustrative duty cycle for Class 8 high-mileage local fleet



Available charging time at home base 2-6 hours

II Illustrative on-site charging need

x 30	264 kWh	1.5	350 kW x 20	→	7 MW
fleet size	effective full charge	max vehicles per charger	on-site chargers needed		incremental service need

III Indicative cost of utility service upgrades

Large utility service upgrades can cost anywhere from

USD 500K – 2.5M per MW

of additional electric load

Cost of utility service upgrade (paid by fleet)

USD 4-18M total

USD ~150-600 K per vehicle

at home base on-duty

Source: NREL; fleet interviews, Roland Berger analysis

For HD local fleets, the potential paths to electrification all involve significant cost and risk:

- If high-capacity charging is prohibitive because of utility cost, there are no good alternatives for fleets:
  - Charging vehicles at lower rates will require additional vehicles to ensure continued operation
  - Rely heavily on public charging (at higher electricity rates and additional operational risk)
- In all cases, the incremental cost needs to get passed down to customers, or negatively hits the profitability of fleets

To remove this roadblock, regulators would need to approve use of ratepayer funding for service upgrades and other "make ready" investments, removing the burden from individual fleets

Even with improved technology, a significant share of the HD local fleet requires access to on-route fast-charging locations, driving investment need of USD 69 B

Investment need for local on-route charging network

Results across Class 3-8
[% requiring on-route charging]

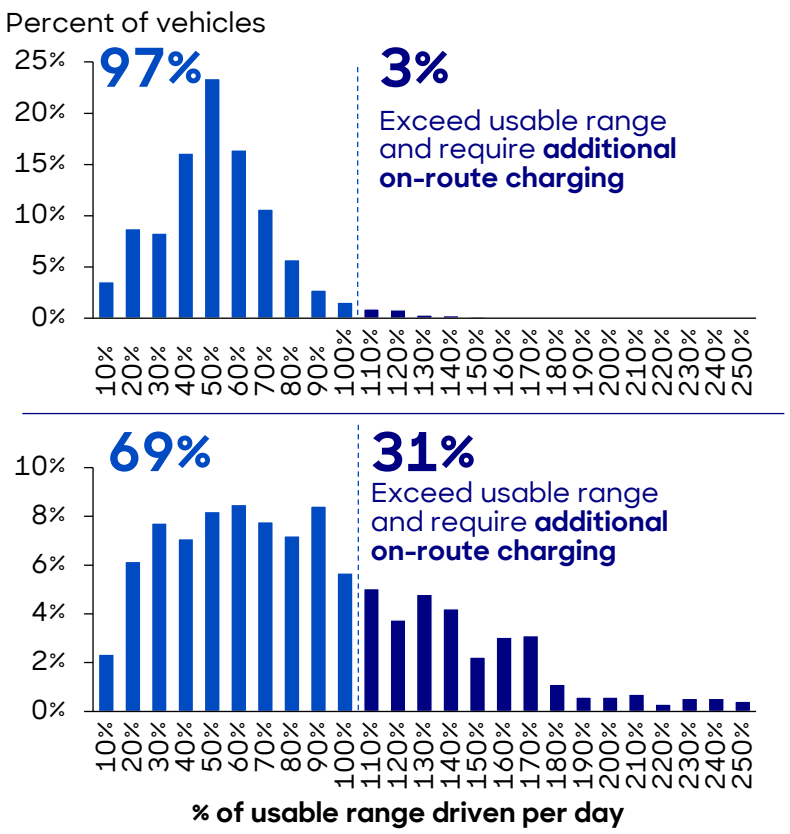
Class 3	100 kWh battery	90 mi usable range	4%	need on-route charging
Class 4	100 kWh battery	90 mi usable range	9%	need on-route charging
Class 5	305 kWh battery	90 mi usable range	3%	need on-route charging
Class 6	305 kWh battery	137 mi usable range	1%	need on-route charging
Class 7	305 kWh battery	137 mi usable range	28%	need on-route charging
Class 8	616 kWh battery	185 mi usable range	38%	need on-route charging

Segment

Medium duty - local

Heavy duty - local

Mileage ratio distribution



Total investment need local on-route charging network [USD]

On-route 500 kW

69 B

Heavy duty vehicles need larger physical footprint at the charging station - likely requiring dedicated charging locations

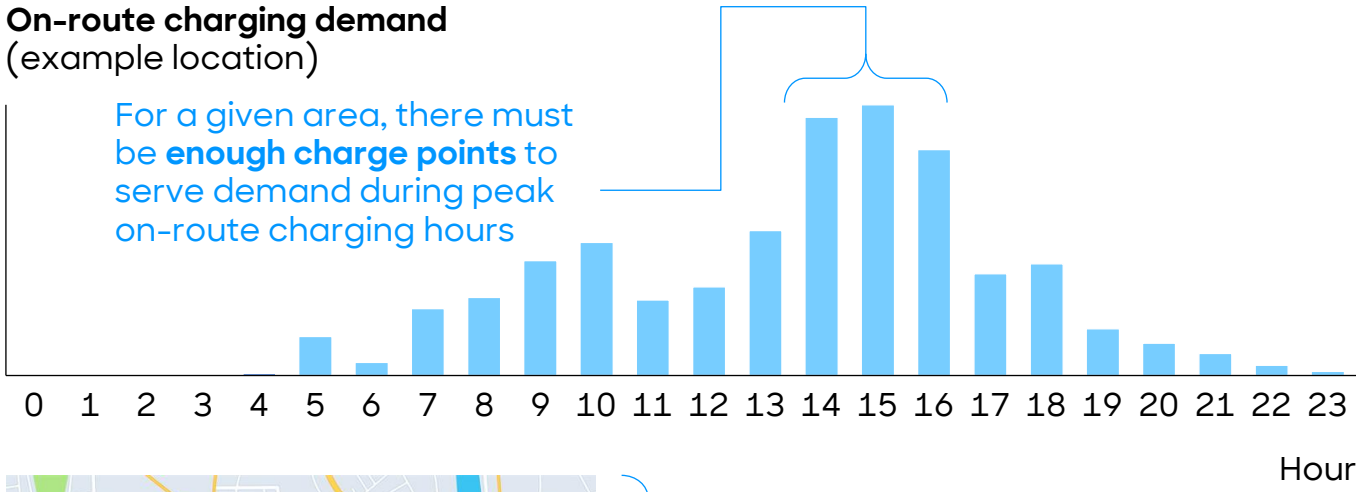
Source: NREL; US Census Bureau, Roland Berger analysis

A reliable local on-route charging network must exist before high mileage vehicles can electrify, but utilization risk poses a major challenge to investment

Challenges and investment hurdles for on-route charging

A sufficiently dense network needs to exist to avoid queueing …

On-route charging demand
(example location)



Further, those charge points must be geographically dispersed such that they **align with fleet traffic volumes and existing routes**

… but the investment case to develop such a network is very challenging …

- **Timing & adoption:** given that significant adoption of high-mileage vehicles will not occur before a sufficient network exists, there is a **"first mover disadvantage"**
- **Utilization & economics:** at full density, individual locations may see **low utilization rates**, which would require **large price premiums** at the plug (which fleets would have to absorb)

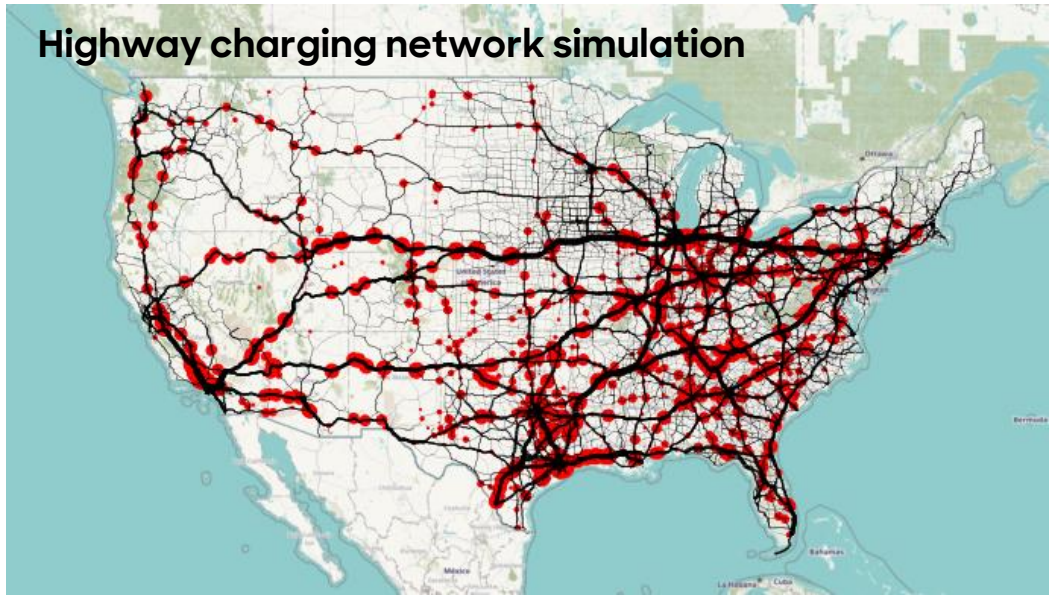
- **Planning and coordination needed to ensure efficient sizing and placement of chargers**
- **Economic support may be required to overcome utilization risk**
- **Concern over utility ownership of public charging infrastructure remains a key regulatory uncertainty**

Source: Expert interviews, Roland Berger analysis

To support full electrification of long-haul vehicles, USD 57 bn need to be invested in converting truck stops into a sufficiently dense charging network

Investment need for highway charging network

Highway charging locations have been simulated across rural and metro areas …



Land cost and space constraints may challenge development, esp. in metro areas

… and each one will need to deploy significant fast charging and overnight charging infrastructure in order to electrify:

Average number of charge points per location:

Rural	Fast chargers	20-25
	Overnight chargers	150-200
Metro	Fast chargers	30-45
	Overnight chargers	200-300

Total investment need highway charging network [USD]

L3 Overnight	On-route 1 MW
30 B	27 B

Total highway charging investment

57 B

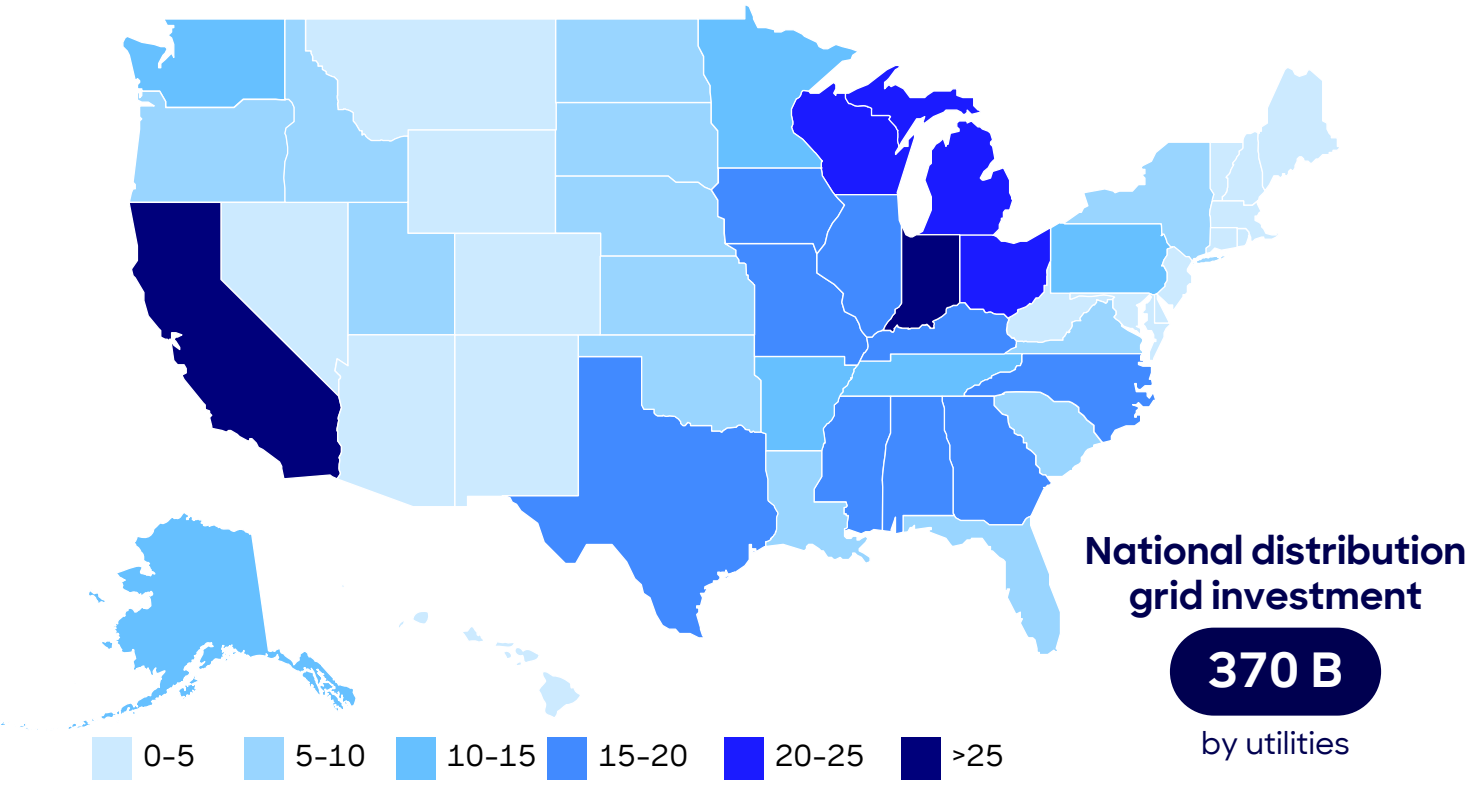
●●● Traffic volume of long-haul combination trucks at simulated charging locations (charging stations will also be utilized by OTRBs)

Source: NATSO; DOT Freight Analysis Framework; Roland Berger Analysis

Nationally, utilities will need to invest around USD 370 billion[1] on distribution grid upgrades and new builds to serve local charging demand[2] from MDHD vehicles

Distribution system investment need - nationwide

Total distribution system investment by state [USD bn]



National distribution grid investment

370 B

by utilities

Challenges and constraints:

- **Utilities will need to build** infrastructure ahead of demand **ahead of MDHD adoption** to avoid bottlenecks and delays
- However, these investments require more **sophisticated grid planning** as well as **regulatory support** – both limited to date
- The overall **pace of utility investment** will still be **constrained** by the need to control rate increases and **maintain affordability**

Potential mitigating factors:

- **This analysis shows** the grid impacts and investment need given **"unmanaged" charging**
- If fleets were able to **shift or manage peak charging** load (e.g. with battery-integrated chargers), **utility investment could be significantly reduced**
- However, **appropriate incentives** and/or price signals would need to exist **to support fleet economics**

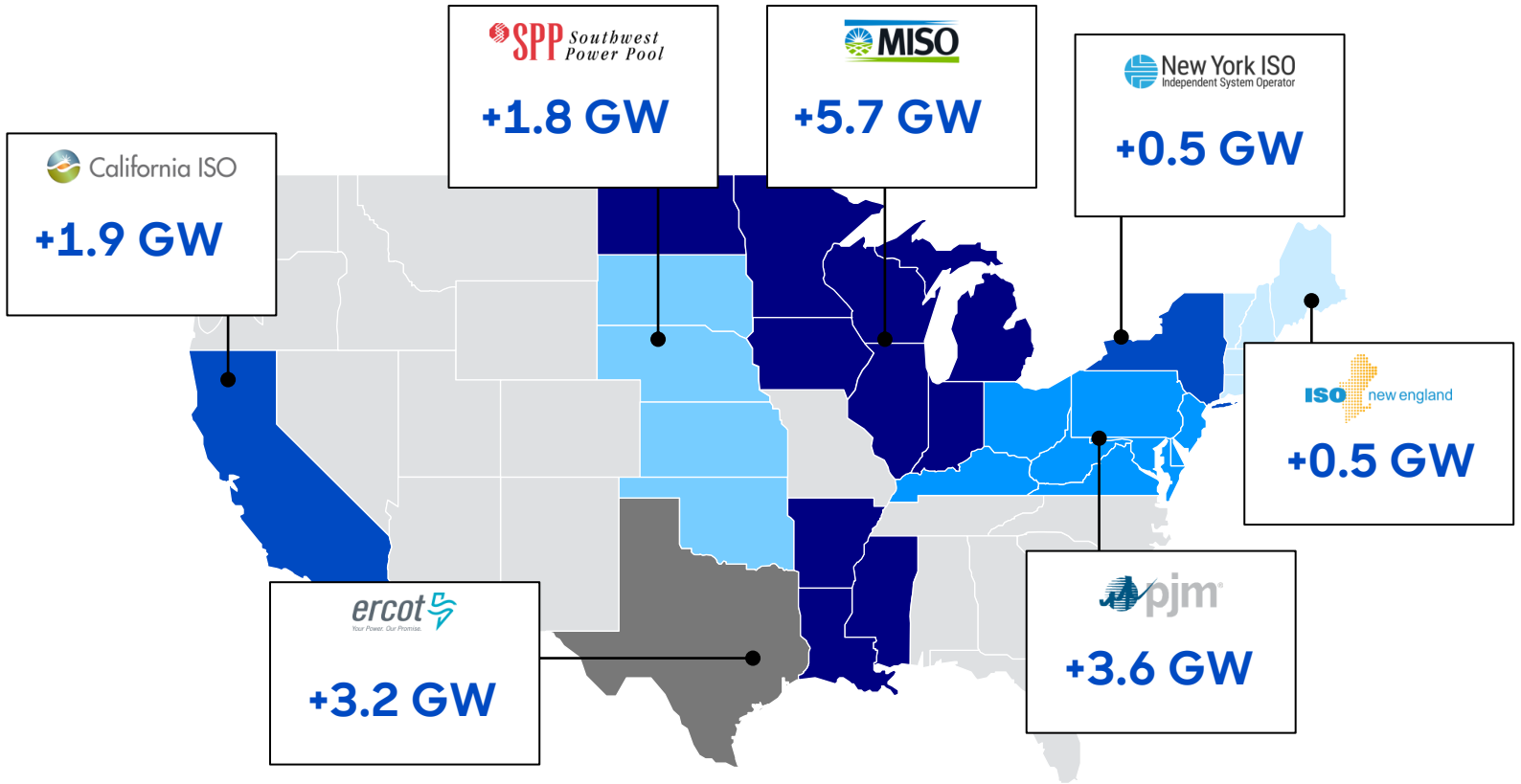
1) Based on "overnight" capital cost of grid infrastructure at current price levels - actual utility investment will be higher due to 1) price inflation of labor and equipment, and 2) Utility guaranteed rate of return
2) Distribution grids will serve on-site and on-route charging demand from local fleets - long-haul trucks / highway charging stations will be served by the transmission grid and bulk power system

Source: NREL, US Census, Roland Berger analysis

While there will be some incremental capacity need (and investment need) created by MDHD charging…

MDHD charging – impact to annual system peak load by ISO

Incremental coincident peak demand [GW]



Incremental investment in generation and transmission capacity:

Generation

22 B

Transmission

12 B

Based on EIA forecasted mix of resource additions and forecasted capital costs (by year of addition) through 2040

Source: EIA AEO 2023, S&P Capital IQ, ISONE 2050 Transmission Study, Roland Berger analysis

…power system operators are already planning for significant generation and capacity growth from transportation electrification, as well as from other trends

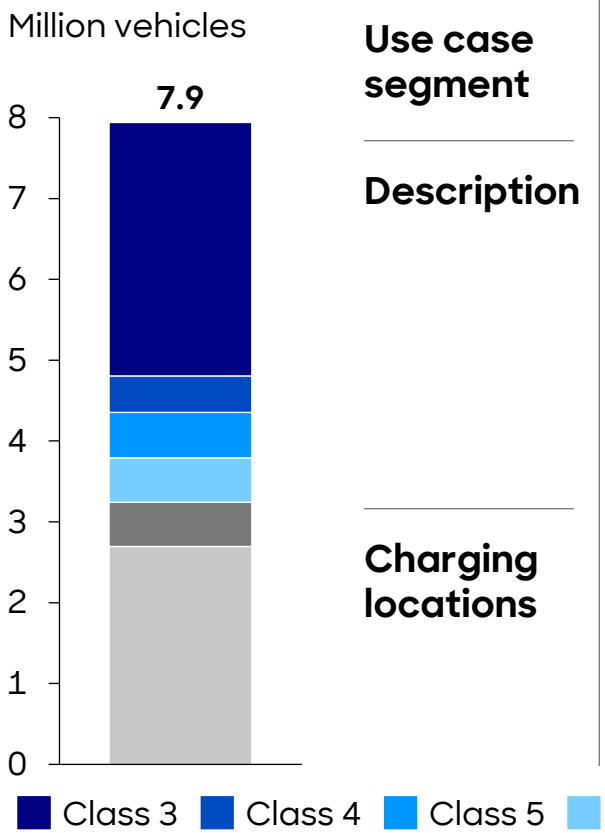
MDHD load impact vs ISO forecasts of overall load growth

ISO region	Generation				Capacity			
	2022 annual generation [GWh]	MDHD charging [GWh]	Increase from MDHD [incremental % of 2022]	2040 ISO load forecast [incremental % of 2022]	2022 peak load [GW]	MDHD peak impact [GW]	Increase from MDHD [incremental % of 2022]	2040 ISO load forecast [incremental % of 2022]
SPP Southwest Power Pool	283,187	19,932	**7%**	**48%**	53	1.8	**3%**	**26%**
MISO	665,254	64,493	**10%**	**17%**	120	5.7	**5%**	**18%**
pjm	795,214	45,998	**6%**	**39%**	148	3.6	**2%**	**20%**
California ISO	223,677	30,980	**14%**	**68%**	52	1.9	**4%**	**42%**
ISO new england	118,887	8,180	**7%**	**46%**	25	0.5	**2%**	**72%**
ercot	429,895	31,556	**7%**	**58%**	80	3.2	**4%**	**29%**
New York ISO Independent System Operator	152,681	8,284	**5%**	**34%**	31	0.5	**2%**	**44%**
	Historical	**RB estimate**	**RB estimate**	**ISO forecast**	**Historical**	**RB estimate**	**RB estimate**	**ISO forecast**

Source: ISO long-term load forecasts, Roland Berger analysis

Within the MDHD population, we categorized four broader use case segments that can be mapped to the different charging location types

Use case segments



Use case segment	Medium Duty (Class 3-6)		Heavy Duty (Class 7-8)	
	1 Local (low mileage)	2 Local (high mileage)	3 Local	4 Long-haul
Description	MD vehicles (e.g., P&D, utility service, school buses, walk in vans) where daily driving distance **does not exceed usable range of BEV**	MD vehicles (e.g., P&D, utility service, school buses, walk in vans) where daily driving distance **exceeds usable range of BEV**	**All other Class 7-8** vehicles (e.g., drayage, distribution)	**Over-the-road** vehicles primarily running longer inter-regional routes, incl. trucks and OTRB
Charging locations	**On-site** at depot locations	**On-site** at depot locations, in addition to **on-route** charging at public locations	**On-site** at depot locations, in addition to **on-route** charging at public locations	Both top-up and overnight charging at **highway truck stop** locations

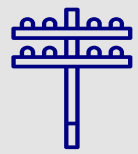
Note: Simulations are based on today's fleet size, except for long-haul trucks. The incremental weight of batteries results in a payload penalty. Trucks that weigh out today would exceed the maximum GVW limit and additional truck capacity is needed to carry the same amount of freight. For each diesel long-haul truck today, ~1.1 battery electric trucks will be needed.

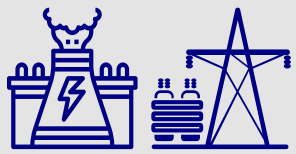
Source: US Census Bureau; Roland Berger Analysis

Our analysis focuses on characterizing the investment needs and challenges across both charging infrastructure and energy infrastructure

Investment landscape analyzed in this study

	Not in scope	Charging infrastructure			Energy infrastructure	
			"Make ready" infrastructure			
	Vehicle	Charger	Site	Electric service	Distribution grid	Generation/ transmission
Investment need	BEV purchase	Charger cost & installation	Civil & electrical	Utility service upgrade	Increased grid capacity	New power system assets
Capital outlay	Fleets	Fleets Developers	Fleets Developers	Fleets Developers Utilities	Utilities	Utilities, IPP's and developers
Subsidies or public funding (including utility rate base)	• Federal EV tax credit • State incentives	• Federal EVSE tax credit • State rebate programs	• N/A	• Utility-side make ready support in some states	• Federal funding available in some cases	• Federal funding available in some cases



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