Analyzing the value of vehicle flexibility to Colorado’s energy system

Final Results, May 2024

Prepared for:

RAP/ICCT

Prepared by:

EER

EVOLVED ENERGY RESEARCH

Contents

- Study purpose and context and modeling methodology
- Scenario design, key assumptions, and sensitivities
- Detailed modeling results

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Study purpose and context

Study purpose and context

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- RAP partnered with Evolved Energy Research to develop a study of the potential **value of vehicle charging flexibility to the broader decarbonized energy system**. RAP chose to focus on the state of Colorado given it has significant ambitions on vehicle electrification.
- Evolved used it's RIO model, using the recently released base case from EER's 2023 Annual Decarbonization Perspective.[1] RIO quantifies both electricity generation cost, but also electricity T&D costs **by tracking peak load over a set of archetypal 'feeders.'** Customer end-use technologies can be made flexible by specifying the **percentage of the native load shape that can be shifted in time**, the **number of hours electric load may be delayed**, and the **customer cost for shifting that load**.
- The goal of the modeling is to be able to **articulate the value of flexible charging to the electricity sector** (and broader energy system as applicable) representing **4 archetypal feeders, residential, commercial, industrial and highway fast charging.**
- Results from this capacity expansion modeling focus on the **system costs from EV adoption with and without flexible charging** and the **competition between vehicle flexibility and other flexible loads.**

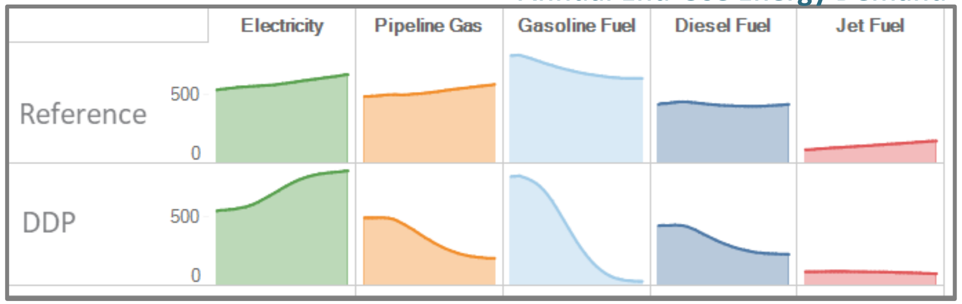
1. EER Releases ADP 2023 (evolved.energy)

EER analytical tools used in this study

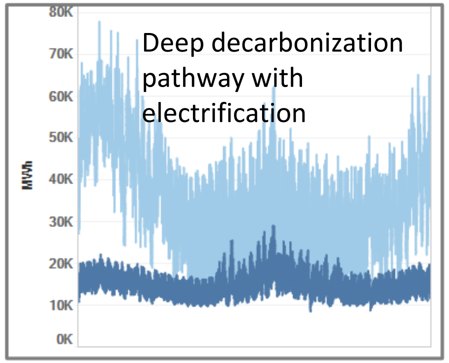
EnergyPATHWAYS (EP) is our demand-side stock-rollover accounting model that produces scenarios based on exogenous service-demand and sale shares

RIO is a supply-side macro-energy model that finds the lowest cost investment and operations plan with best-in-class temporal and spatial granularity

Annual End-Use Energy Demand

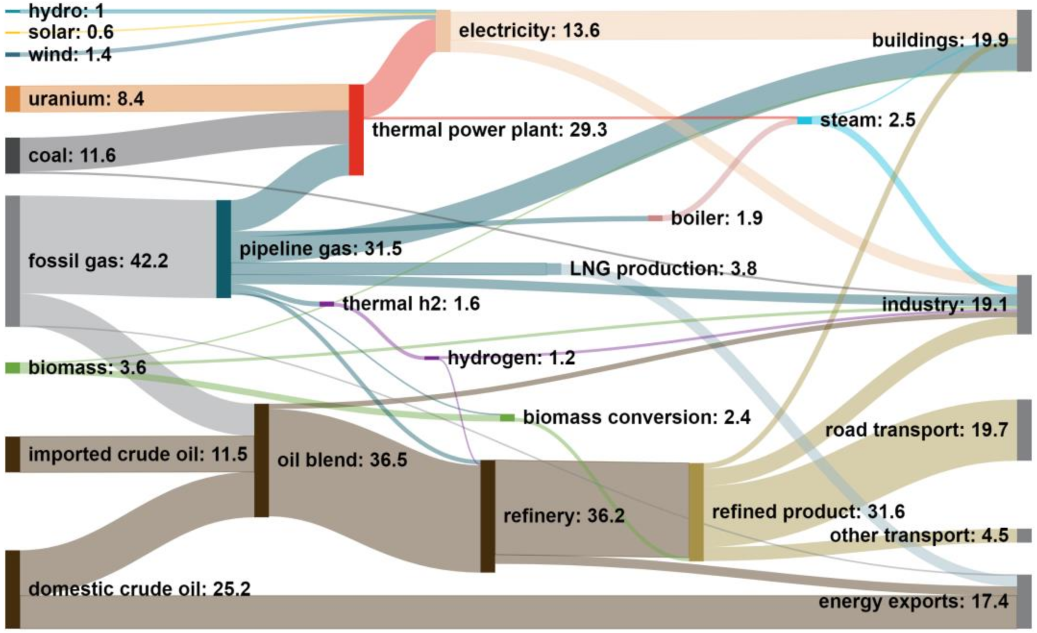


Hourly Load Shape



For this study, EER replaced our EV transport assumptions in EP with ICCT's CO specific demand projections for LDV and MHDV

2021 Energy System



Supply-side modeling

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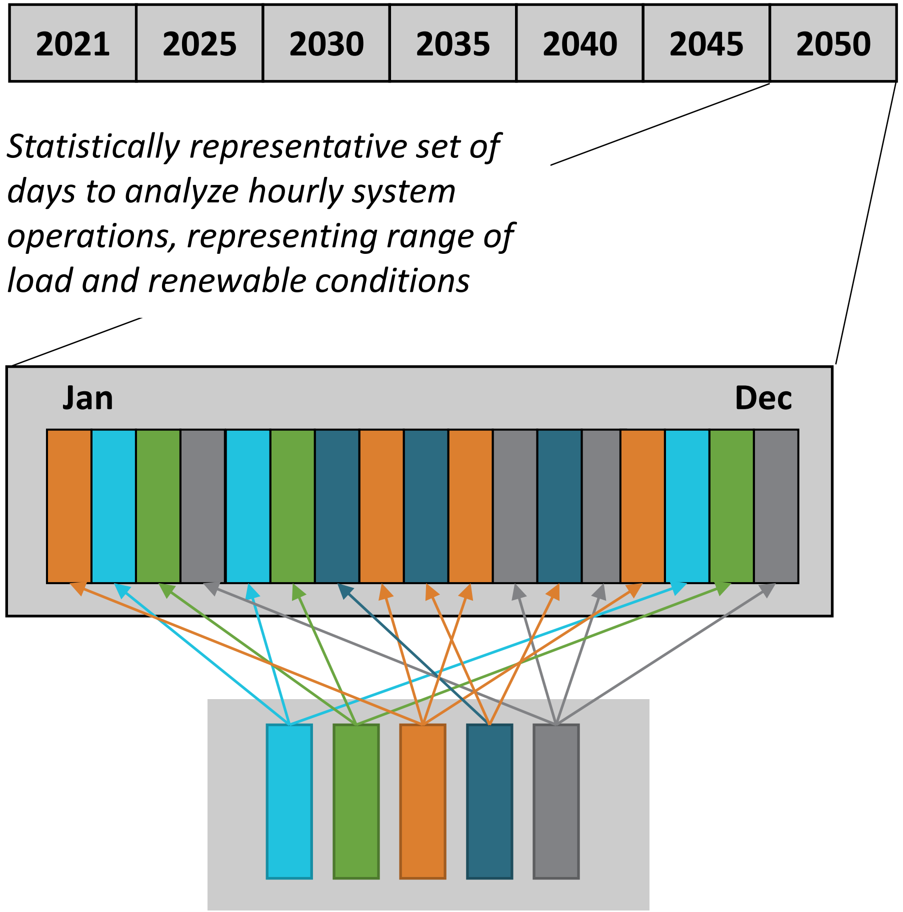
- Capacity expansion tool producing cost-optimal resource portfolios across the electric and fuels sectors
  - Least-cost energy supply mix to achieve emissions targets
- Simulates hourly electricity operations and annual investment decisions
- Electricity and fuels are co-optimized to identify sector coupling opportunities
  - Example: production of hydrogen from electrolysis

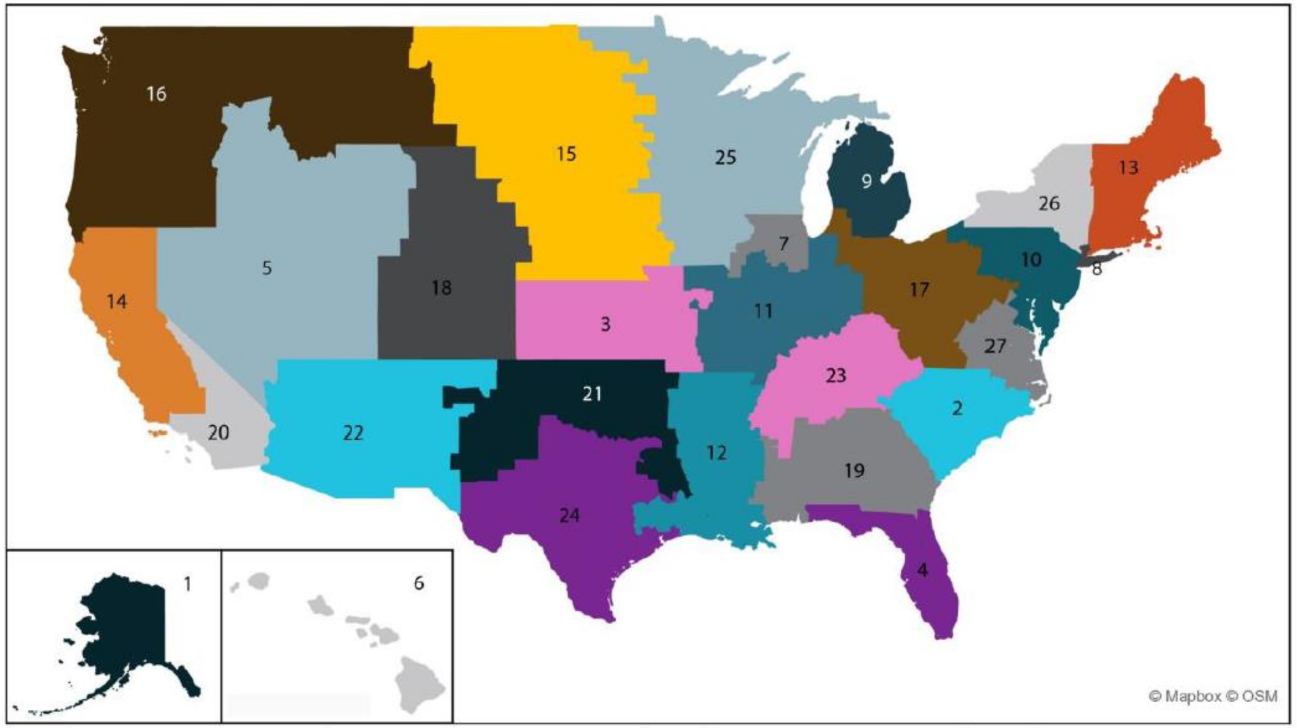
RIO

Co-optimized energy supply

- Electricity
- Pipeline Gas
- Gasoline Fuel
- Diesel Fuel
- Jet Fuel
- Hydrogen

Colorado Case built off of 2023 Annual Decarbonization Perspective which already has regional and temporal granularity





1	Alaska	8	Metropolitan New York	15	Northern Great Plains	22	Southwest
2	Carolinas	9	Michigan	16	Northwest	23	Tennessee Valley
3	Central Great Plains	10	Mid-Atlantic	17	Ohio Valley	24	Texas
4	Florida	11	Middle Mississippi Valley	18	Rockies	25	Upper Mississippi Valey
5	Great Basin	12	Mississippi Delta	19	Southeast	26	Upstate New York
6	Hawaii	13	New England	20	Southern California	27	Virginia
7	Metropolitan Chicago	14	Northern California	21	Southern Great Plains		

hourly operations, 40 sample days per year, state of charge tracking between sample days

Day sampling process

Clustering and validation build a sample to approximate a full-year

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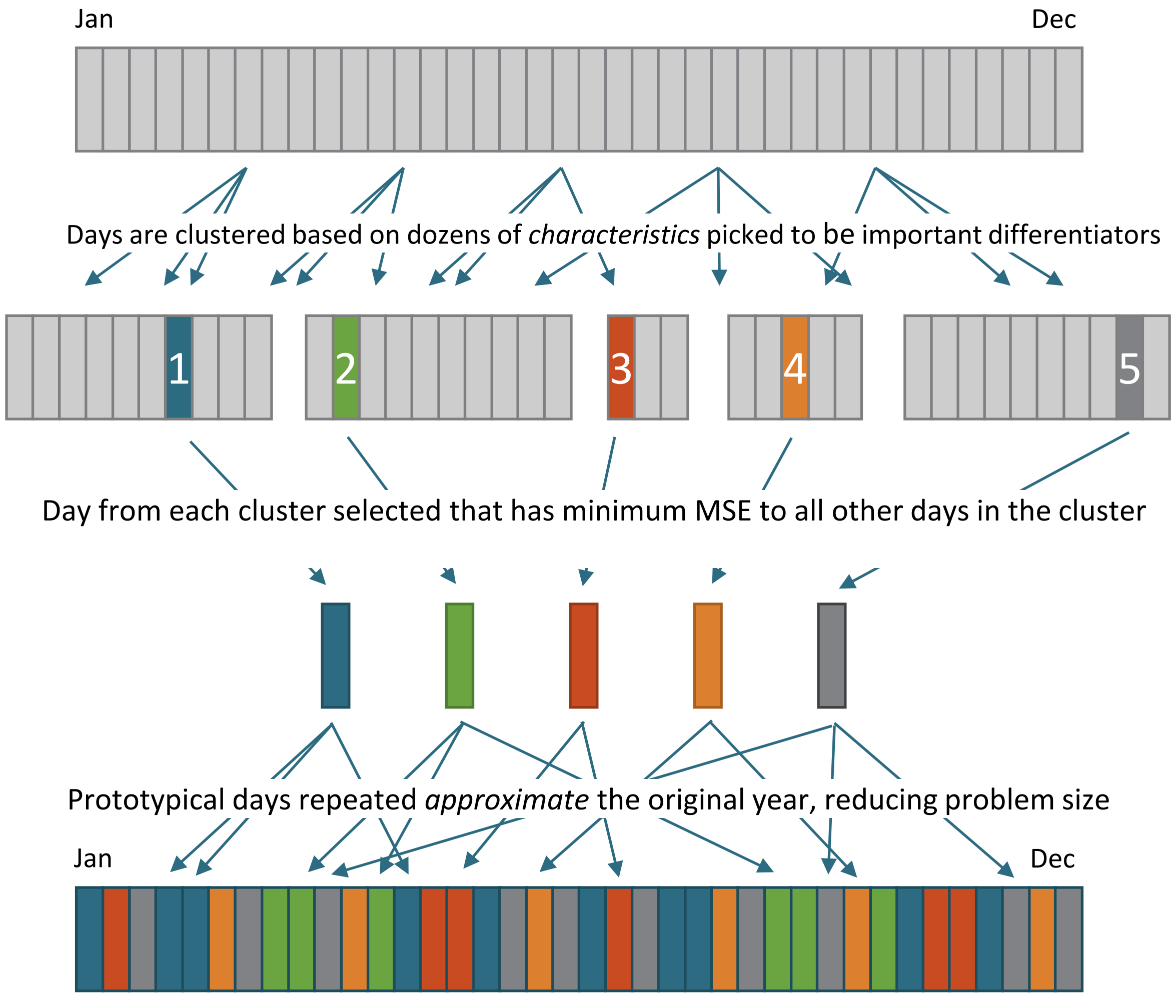

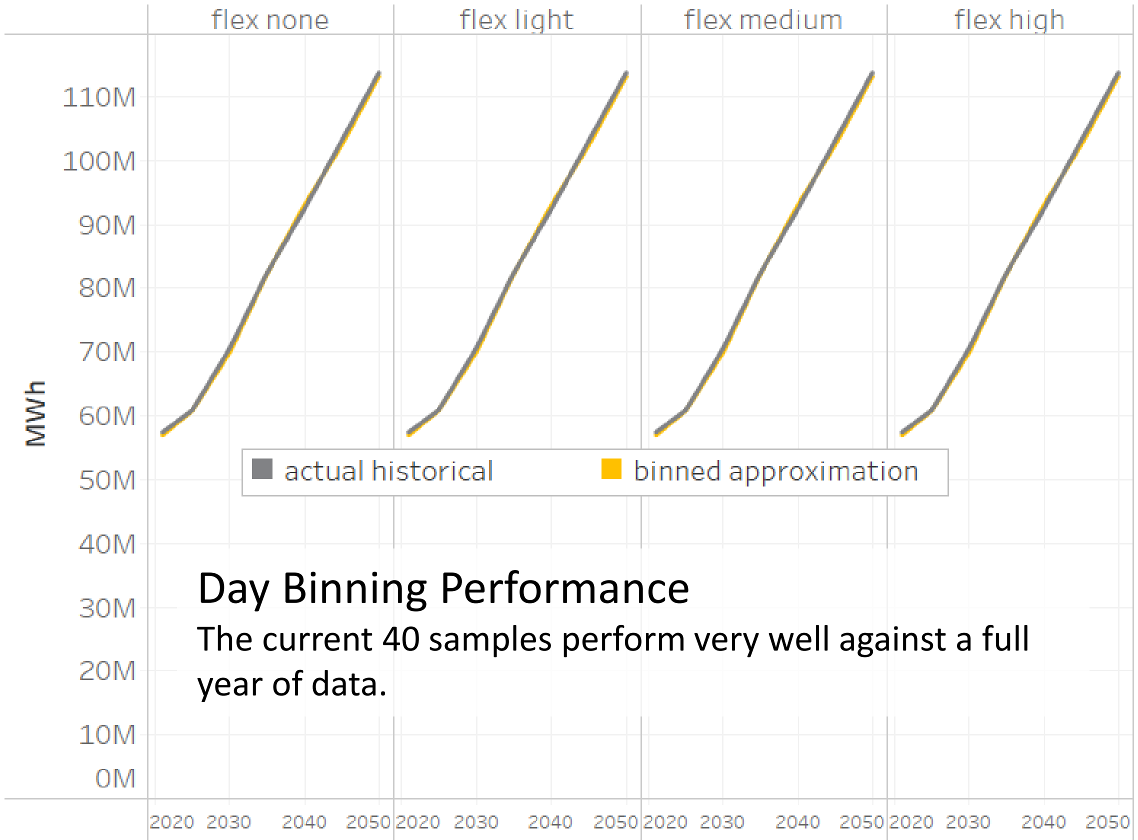

Day Binning Performance

The current 40 samples perform very well against a full year of data.

Each feeder has distinct load across each day, and peak load can occur on different days for each feeder. The day-binning algorithm tracks these variations across feeders and days, and the clustering accounts for this in selecting days.

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Scenarios and Assumptions

Scenario Definitions

Scenario Name	Abbreviated Name	Description
Zero flexibility	ZF	Shows system without any transportation load shifting benefits
Flexibility Light	FL	Assumes no flexibility from HDV and MDV or HWY charging and only 50% of LDV are able to shift in residential applications (4 hours of shifting assumed). Driven by no additional uptake or incentives for level 2 chargers in residential sector and non-energy economics driving charging pattern in MDV and HDV (e.g. high opportunity cost of not reaching full charge)
Flexibility Mid	FM	Assumes minimal HDV and MDV charging flexibility (2 hour delay for overnight charging). No flexibility in HWY charging and 75% of LDV are able to shift (8 hours of shifting assumed). Driven by higher uptake of level 2 chargers and significant continued non-energy economics driving charging pattern in MDV and HDV
Flexibility High	FH	Assumes additional flexibility in HDV, MDV and HWY charging. HWY charging shifting of 4 hours for overnight charging. MDV and HDV shifting of 4 hours for overnight charging. LDV flexibility of increases to up to 24 hour participation in “demand response” like programs with 75% of vehicles participating. Driving patterns and charging profiles show 10% utilization of vehicles on average so this level of response is feasible.

Feeder archetypes

- Evolved modeled 4 archetypal feeders – Residential, Commercial, Industrial and Highway – to better understand the potential for load flexibility
- The shape of other non-transport loads is assigned by feeder type (e.g. shape of residential load (HVAC, lighting, water heating) vs shape of industrial load (motors, heavy equipment, etc)
- We have disaggregated the total load from different vehicle class types and matched them to feeder types
  - LDV vehicles are mapped to residential, commercial and highway feeder types using ICCT data.[1]
  - MHDV vehicles are mapped to commercial, industrial and highway feeder archetypes. Based on EER's ADP service demand, long haul HDV is ~65% in CO, short haul is 8% and the balance is MDV. We assume 75% of long haul HDV should be mapped to highway charging archetype, 25% of long haul and 100% of short haul is mapped to Industry archetype, and 100% of MDV is mapped to the Commercial archetype.
- Our scenarios explore a broad set of future pathways that allow for different levels of flexibility this could be driven by behavior or direct payments, regulatory requirements or access to different technology (e.g. the mix of available chargers changes the ability of the vehicles to respond flexibly to the needs of the electric grid).

1. Colorado LDV charging assumptions from *"Colorado charging infrastructure needs to reach electric vehicle goals". WORKING PAPER 2021-08. February 2021.* [Colorado charging infrastructure needs to reach electric vehicle goals (theicct.org)]

Vehicle electricity demand from ICCT's CO specific studies

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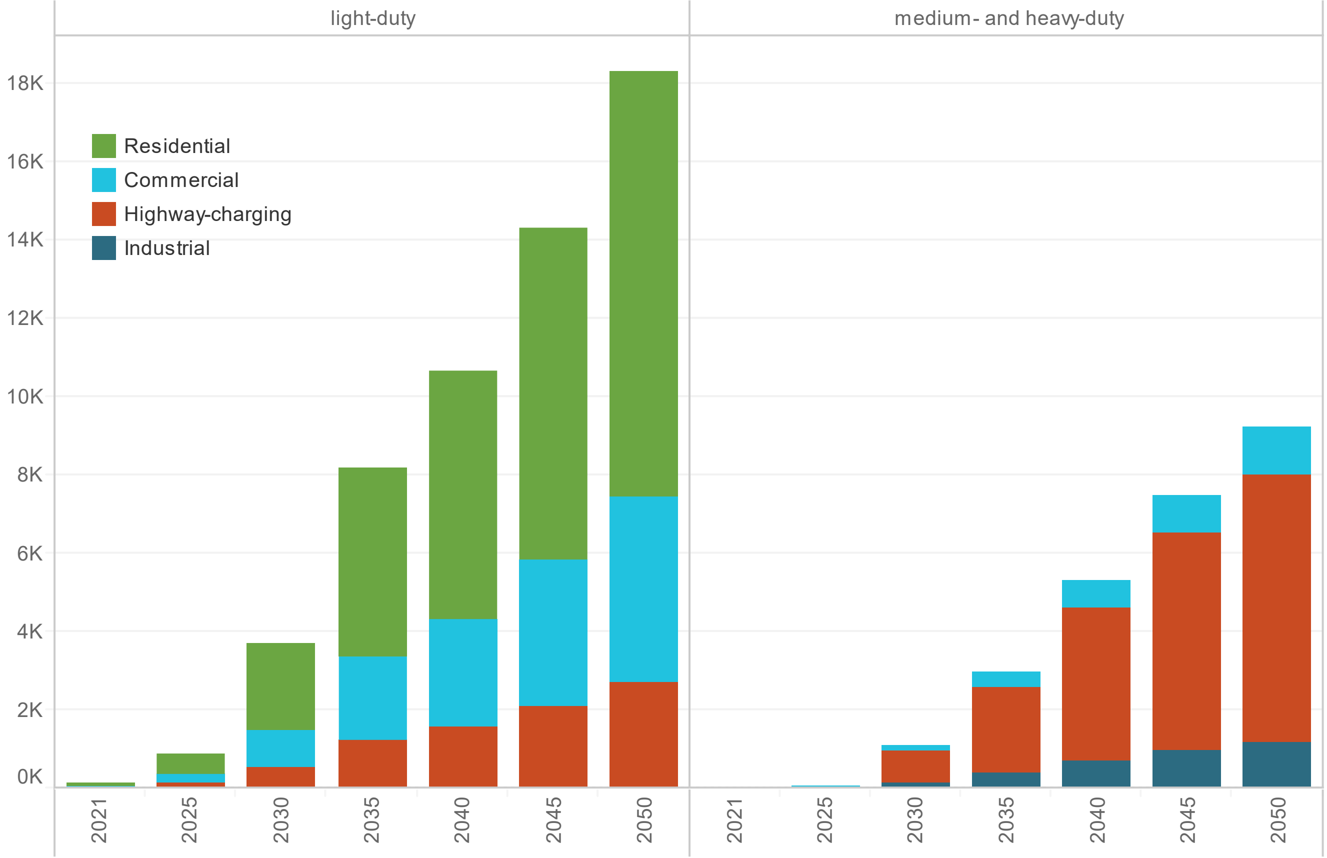
- EER used ICCT's Colorado LDV charging assumptions from *"Colorado charging infrastructure needs to reach electric vehicle goals". WORKING PAPER 2021-08. February 2021*
  - Home charging was allocated to residential feeder archetype, workplace and non-residential level 2 was allocated to commercial feeder archetype and DCFC was allocated to HWY feeder archetype
- Colorado MHDV charging assumptions from Benefits of Adopting California Medium and Heavy-Duty Vehicle Regulations. 2022.
  - *We used the updated fact sheet for Colorado. Found here:*

Vehicle Loads Adpated from ICCT

GWh



LDV Assumptions

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	Scenario 2 – Flex Light[1]			Scenario 3 – Flex Medium			Scenario 4 – Flex High		
	RES	**COM**	**HWY**	**RES**	**COM**	**HWY**	**RES**	**COM**	**HWY**
Share of GWh on feeder[2]	61%	25%	14%	61%	25%	14%	61%	25%	14%
Share level 2 charging or faster	58%	100%	100%	80%	100%	100%	100%	100%	100%
% level 2 or faster shifted	50%	0%	0%	75%	25%	0%	75%	50%	0%
Maximum hours delay	4	0	0	8	2	0	24	4	0
Customer cost of shift [$/MWh]	$2	$2	$2	$2	$2	$2	$2	$2	$2

1 The Flex Light scenario aligns with the ICCT share of residential level 1 and level 2 chargers

2 The share of energy by feeder type aligns with the ICCT values over all scenarios, and varies slightly by year. The values in the chart are the average for that application type.

Data sources and assumptions – MHDV

	Scenario 2 – Flex Light			Scenario 3 – Flex Medium			Scenario 3 – Flex High		
	COM	IND	HWY	COM	IND	HWY	COM	IND	HWY
Share by feeder[1]	25%	25%	50%	25%	25%	50%	25%	25%	50%
% load shifted	0%	0%	0%	50%	50%	50%	75%	75%	75%
Number of hours shifted +/-	0	0	0	4	4	2	8	4	4
Customer cost of shift	0	0	0	$1/MWh	$2/MWh	$50/MWh	$1/MWh	$2/MWh	$50/MWh

1. based on ADP service demand, long haul hdv is ~65% in CO, short haul is 8% and the balance is mdv. Allocation method, 75% of long haul hdv = highway, 25% of long haul hdv and 100% of short-haul = productive, 100% of mdv = commerical

Modeling CO policy and electricity system

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- EER modeled Colorado's emission reductions for the electricity sector as equivalent to a clean energy standard, achieving 100% clean by 2050
  - The state's plans for electricity emissions beyond 2030 are still in flux, so we used Xcel Energy's commitment of an 80% reduction in emission by 2030, and 100% clean by 2050 for the whole state.
- Since we are modeling the state in isolation, we have constrained the growth of renewables and electrolysis
  - Annual renewable builds are assumed to rise to the maximum historical build seen in the state by 2025, with the potential to continue to grow 14.4% annually through 2034, and 7.2% afterward, based on economics shaped by incentives and policy constraints
  - Electrolysis is limited to displacing existing hydrogen demand in the state and growing transportation demand based on ADP2023's IRA scenario.

Sensitivities modeled

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- Evolved modeled several sensitivities to explore different ways the CO energy system may evolve.

1. High Residential LDV charging sensitivity
   - Change total GWh from ICCT assumptions (top row on LDV assumptions page) to different overall allocation, increasing Residential from 61% to 80% Residential, (Res 80%, Com 10%, HWY 10%)
2. High Commercial LDV charging sensitivity
   - Change total GWh from ICCT assumptions (top row on LDV assumptions page) to different overall allocation, increasing commercial from 25% to 45% (Res 41%, Com 45%, HWY 14%)
3. Different renewable supply mix
   - High Solar sensitivity and a No CCS sensitivity
4. No Customer Cost Differentiation
   - No $50/MWh on MHDV highway charging

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Detailed Modeling Results

Vehicle flexibility has potential to provide substantial energy system value

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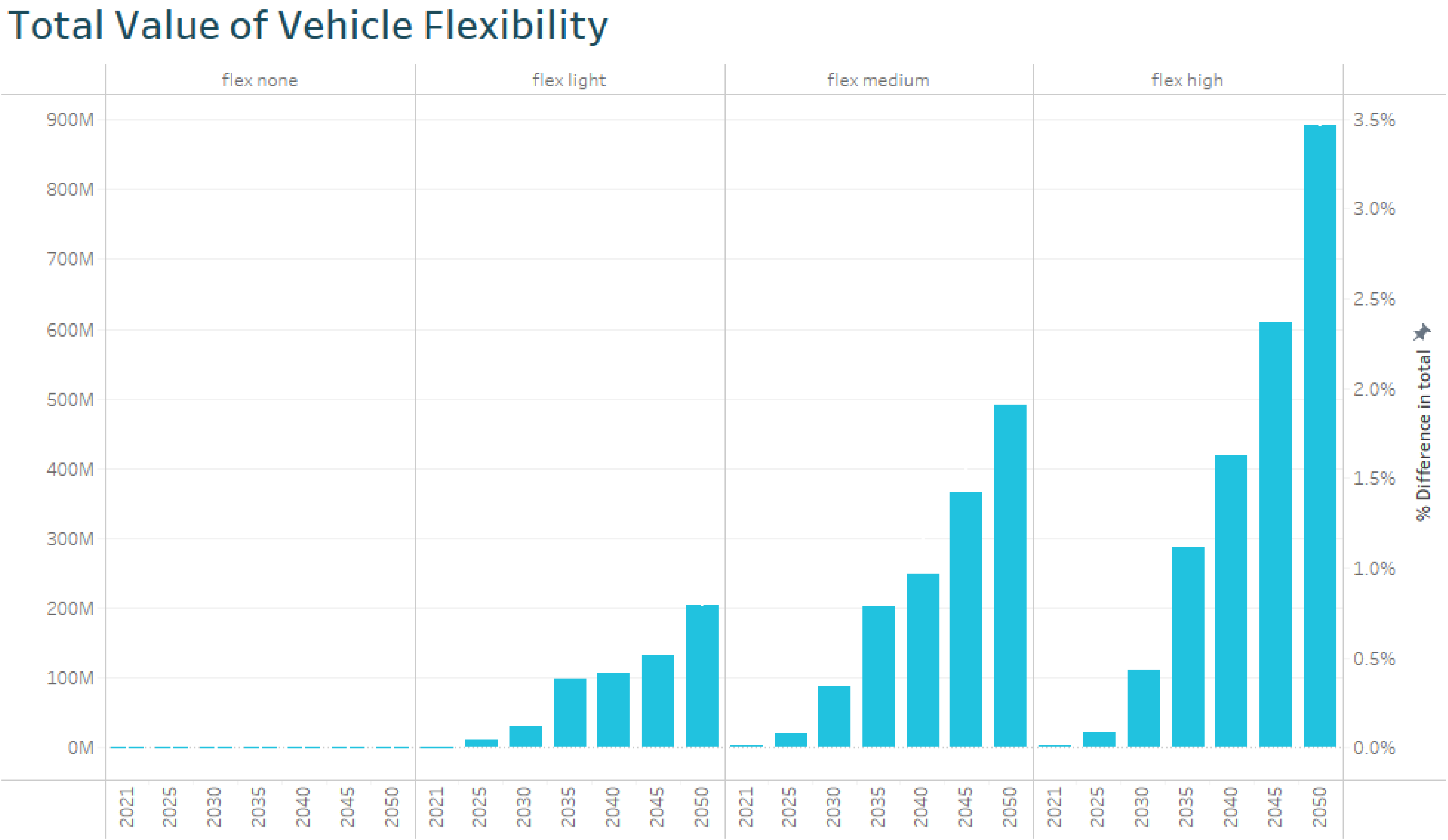
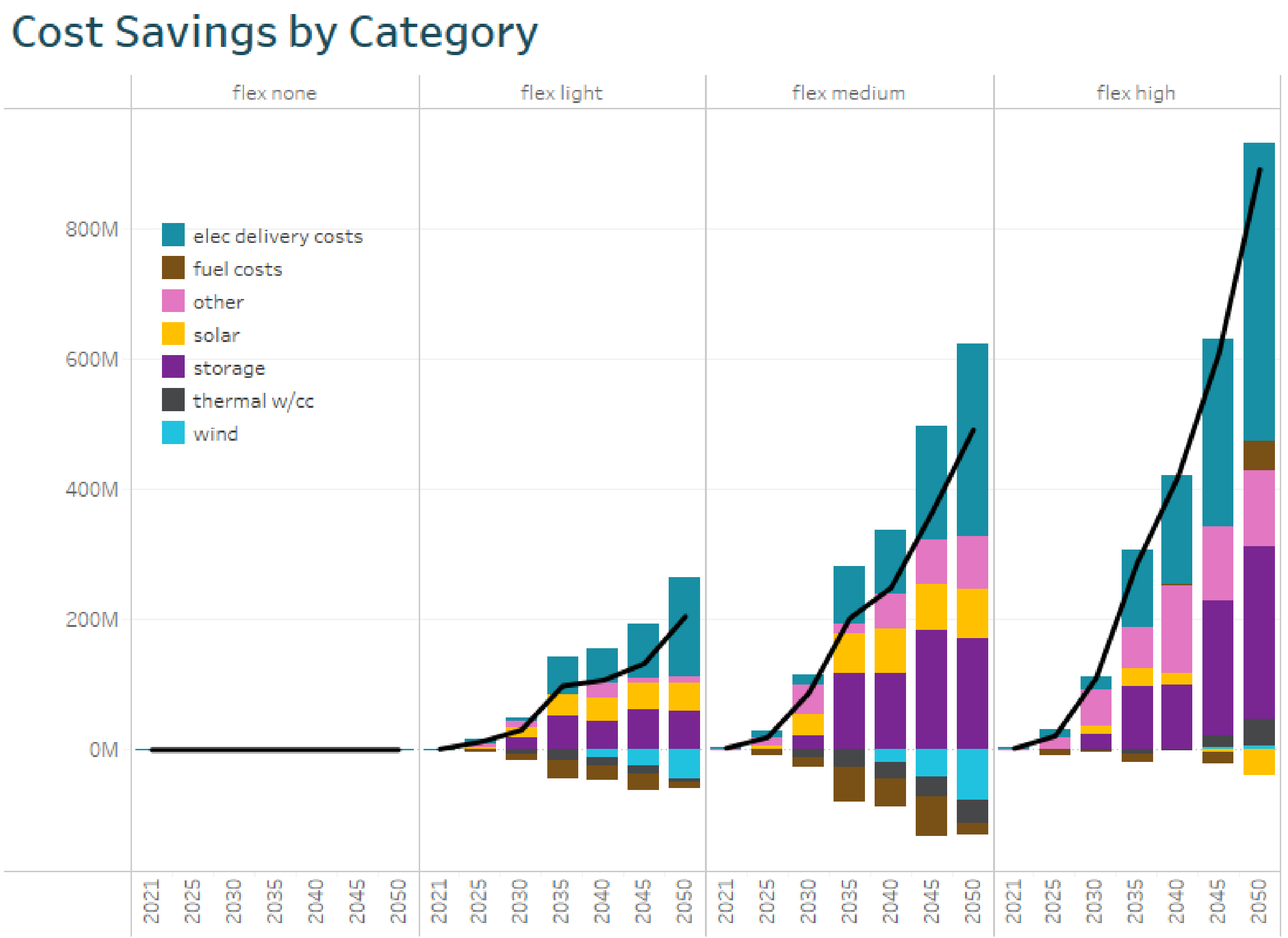
- Total value ranges from $100-$300M/yr in 2035 and $200-$900M/yr by 2050
- The flex high scenario delivers significantly more value
- A further breakout of the costs and benefits that build up to these summary net costs will be shown in the next few slides



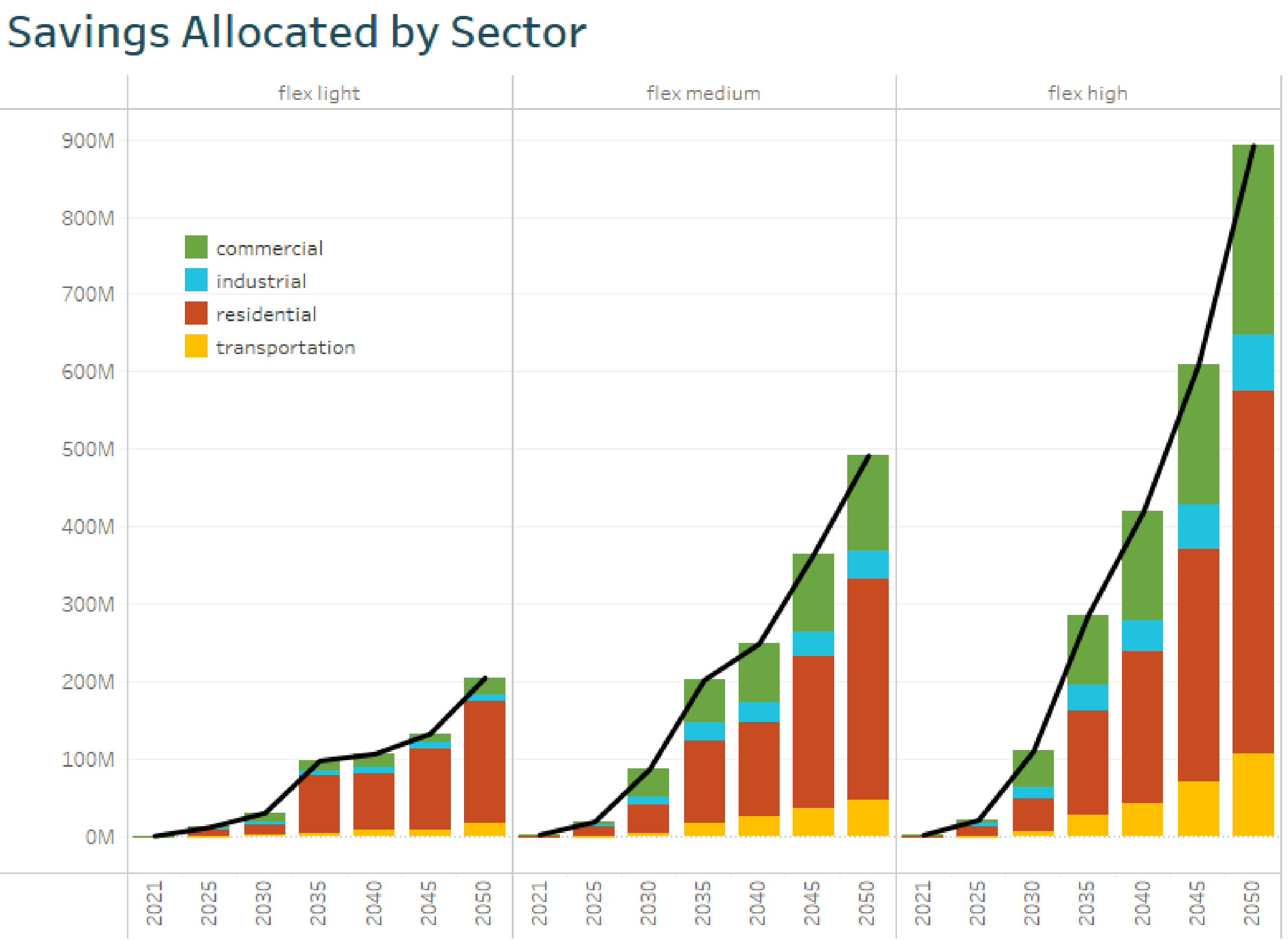
Cost savings mostly from avoided capital investments in storage, solar and distribution system

- Flexibility flattens system peaks reducing the need for electricity grid upgrades
- Vehicle flexibility reduces need for capital investments in storage and solar
- With enough vehicle flexibility the system is able to avoid thermal investment instead of just optimizing renewable and storage supply investments



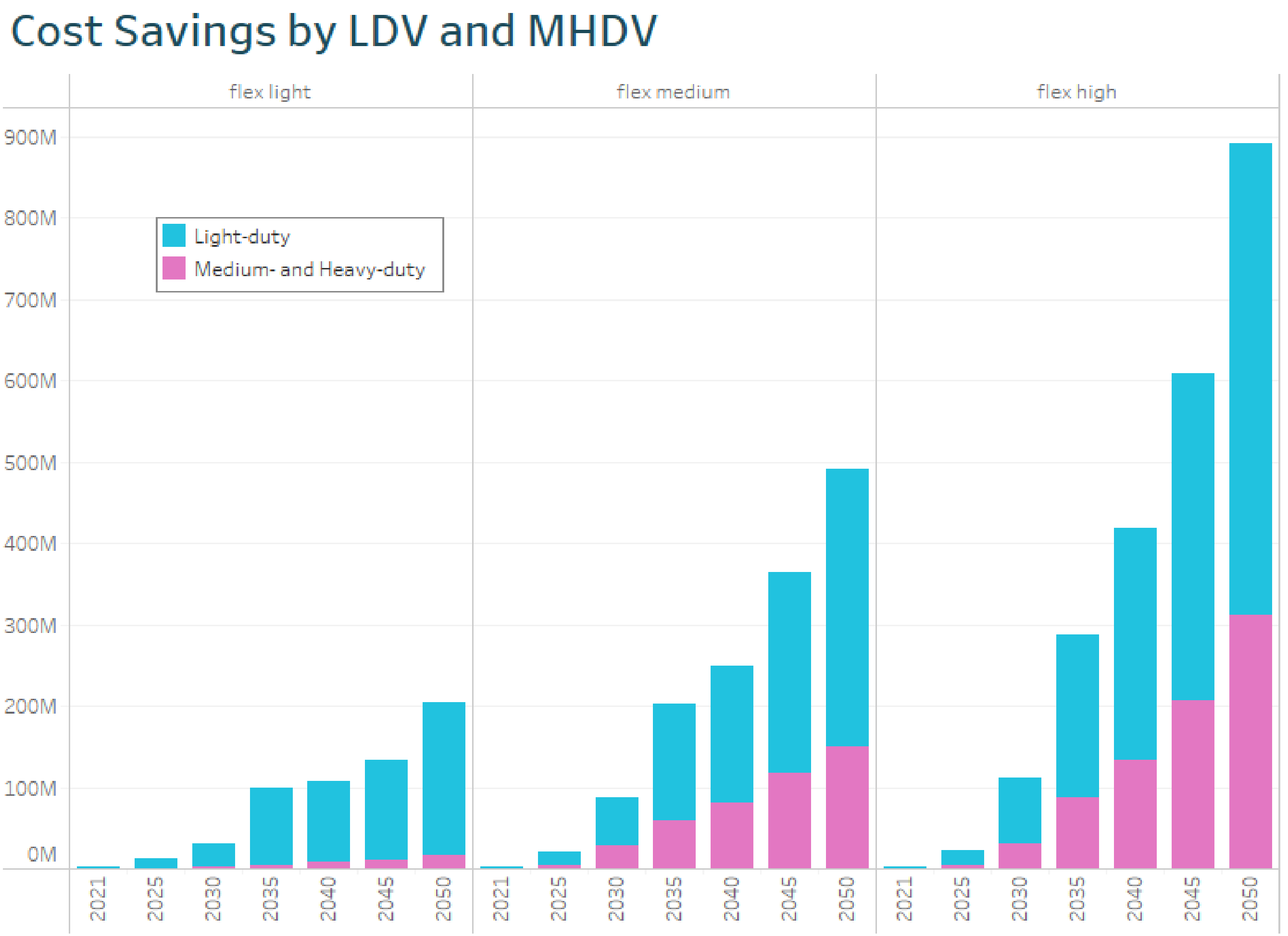
Value created by vehicle charging in different sectors and archetype feeders

- Majority of savings driven by residential charging flexibility in all scenarios but particularly in the flex high scenario
- Majority of the expected EV load comes from LDV
- Residential sector has a larger potential for avoided distribution costs



LDV represent majority of the savings, MHDV savings become significant in flex high scenario

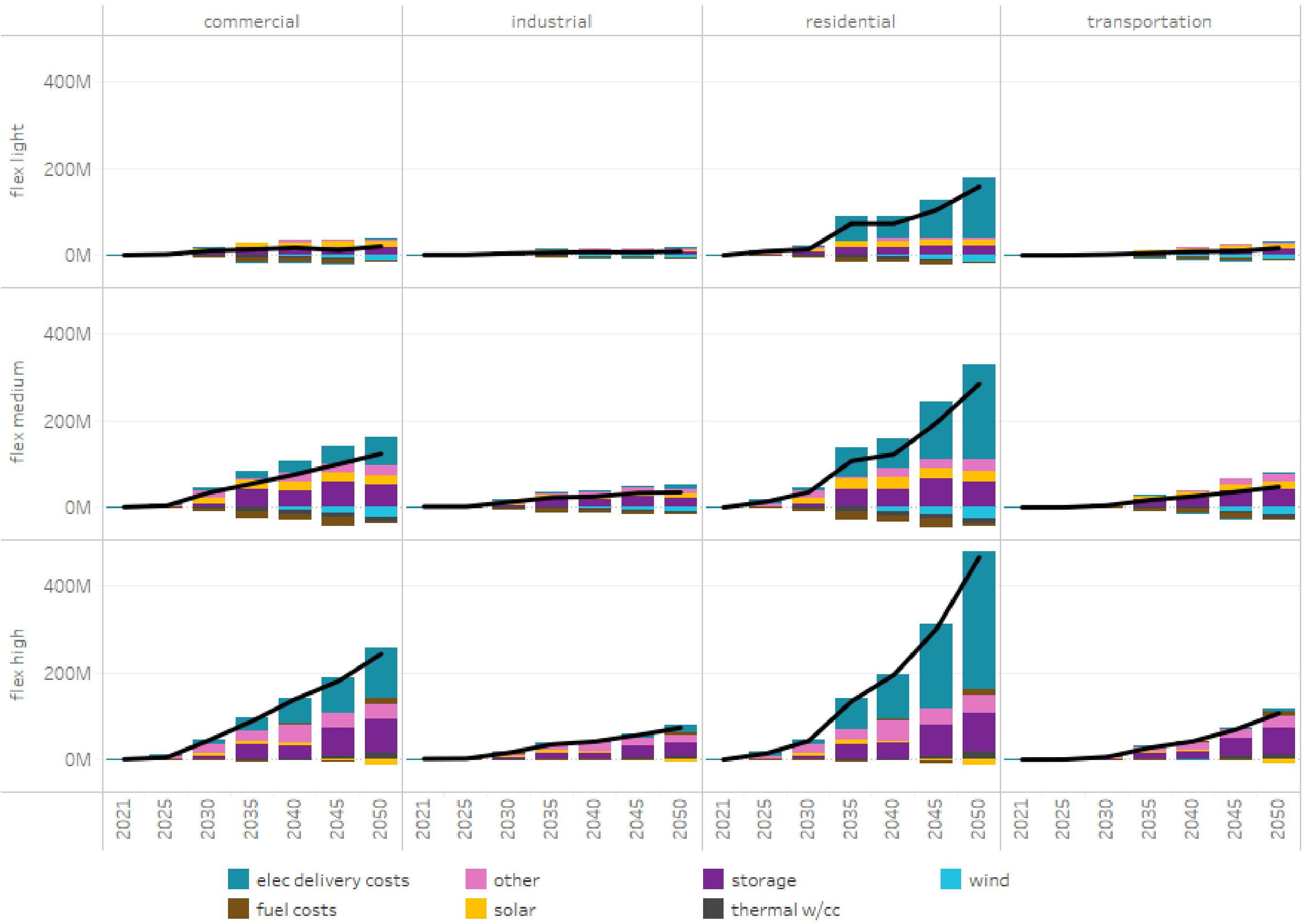
- Breaking out savings by LDV and MHDV, it is clear that LDV represent the majority of the savings
- MHDV savings become more significant in the flex high scenario



Residential and commercial applications drive majority of flexibility value

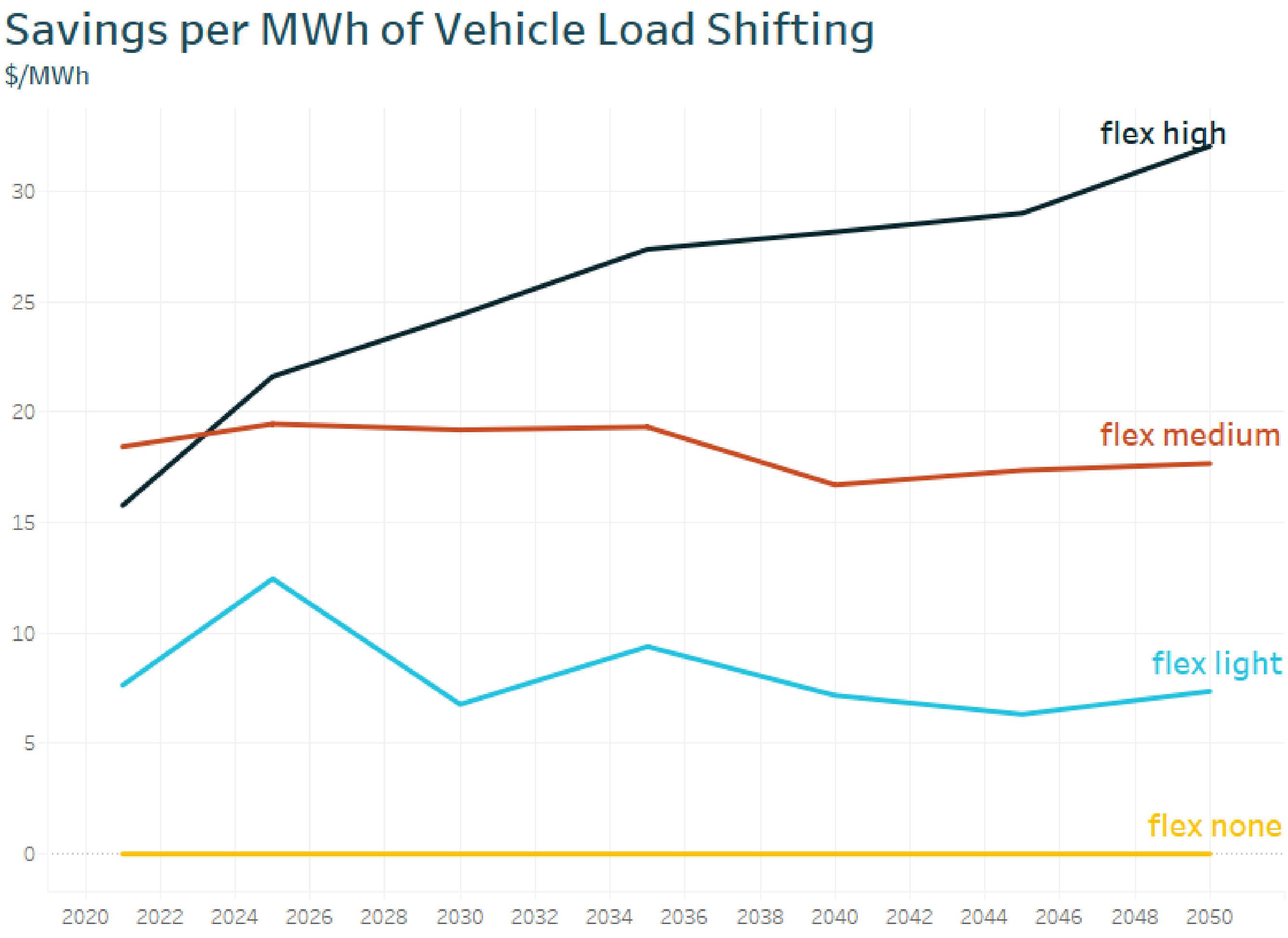
- Residential flexibility value largely from avoided T&D delivery costs and some reduced supply investment
- Limited benefits to highway (transportation) charging could be due to less opportunity to arbitrage broader system load shape

Savings by Category and Sector/Feeder



Change in total investment/sales

- Total savings from $7/MWh-$30/MWh
- Shows that programs need to unlock inherent flexibility, not enough to overcome other non-energy economics
- Savings per MWh of shifting relatively flat for flex light and flex medium



Net present value of residential charging flexibility translated to number of L2 chargers @ 100% incentive

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Residential Value Associated with Level 2 chargers

	2030	2035	2040	2045	2050
Flex Light	$ 13,893,000	$ 73,346,000	$ 73,219,000	$ 104,639,000	$ 158,418,000
Flex Medium	$ 35,259,000	$ 107,340,000	$ 122,678,000	$ 195,563,000	$ 285,396,000
Flex High	$ 43,023,055	$ 134,418,000	$ 195,777,000	$ 302,089,000	$ 467,356,000

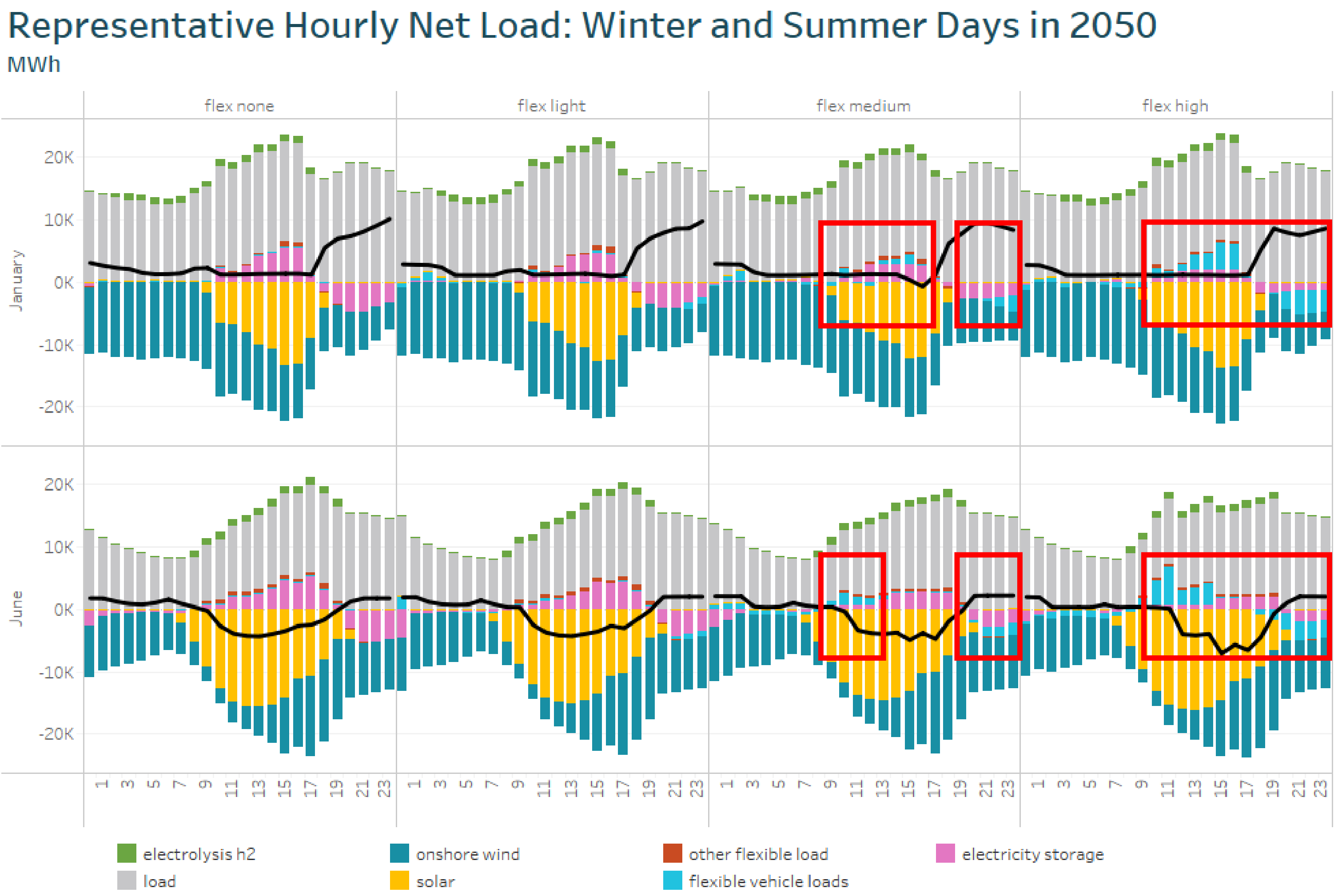
NPV (10 year lifetime energy system value) of level 2 charger investment

	2030 NPV	L2 chargers (100% incentive)	2040 NPV	2040 L2 chargers (100% incentive)
Flex Light	$396,953,346	171,693	$788,067,498	394,034
Flex Medium	$607,433,298	262,731	$1,316,991,272	658,496
Flex High	$753,155,660	325,759	$2,014,575,905	1,007,288

Note: NPV uses a 7% rate, 10 year life and a $2312/L2 charger in 2030, and $2000/L2 charger in 2040

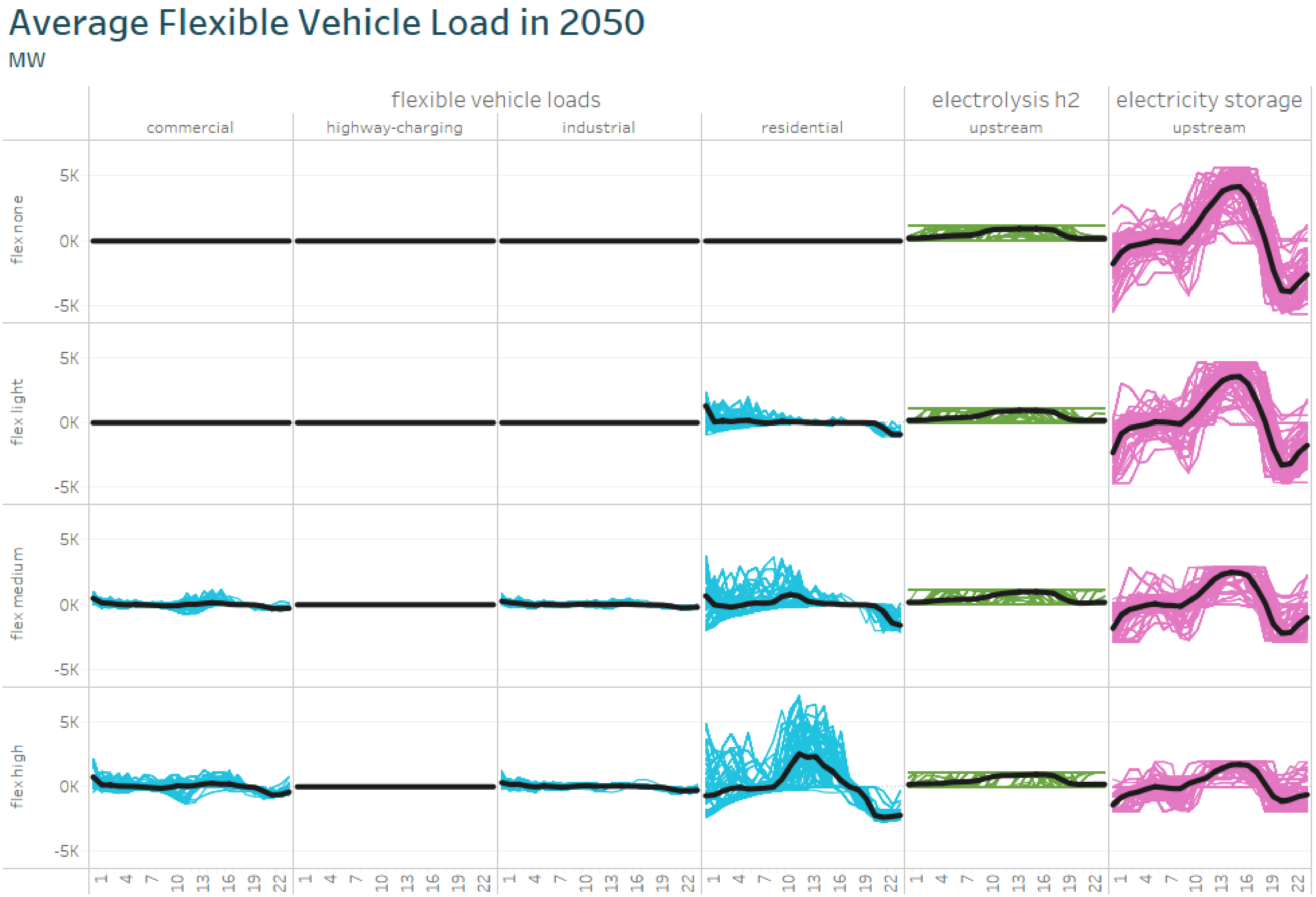
Hourly dispatch on representative winter and summer load days

- Renewable diversity in Colorado reduces overall need for flexibility
- Pattern is similar in winter and summer
- Electrolysis is shaping load during solar hours when energy is less expensive as it is built for exogenous demand
- Vehicle flexibility competes with storage in more hours in flex high



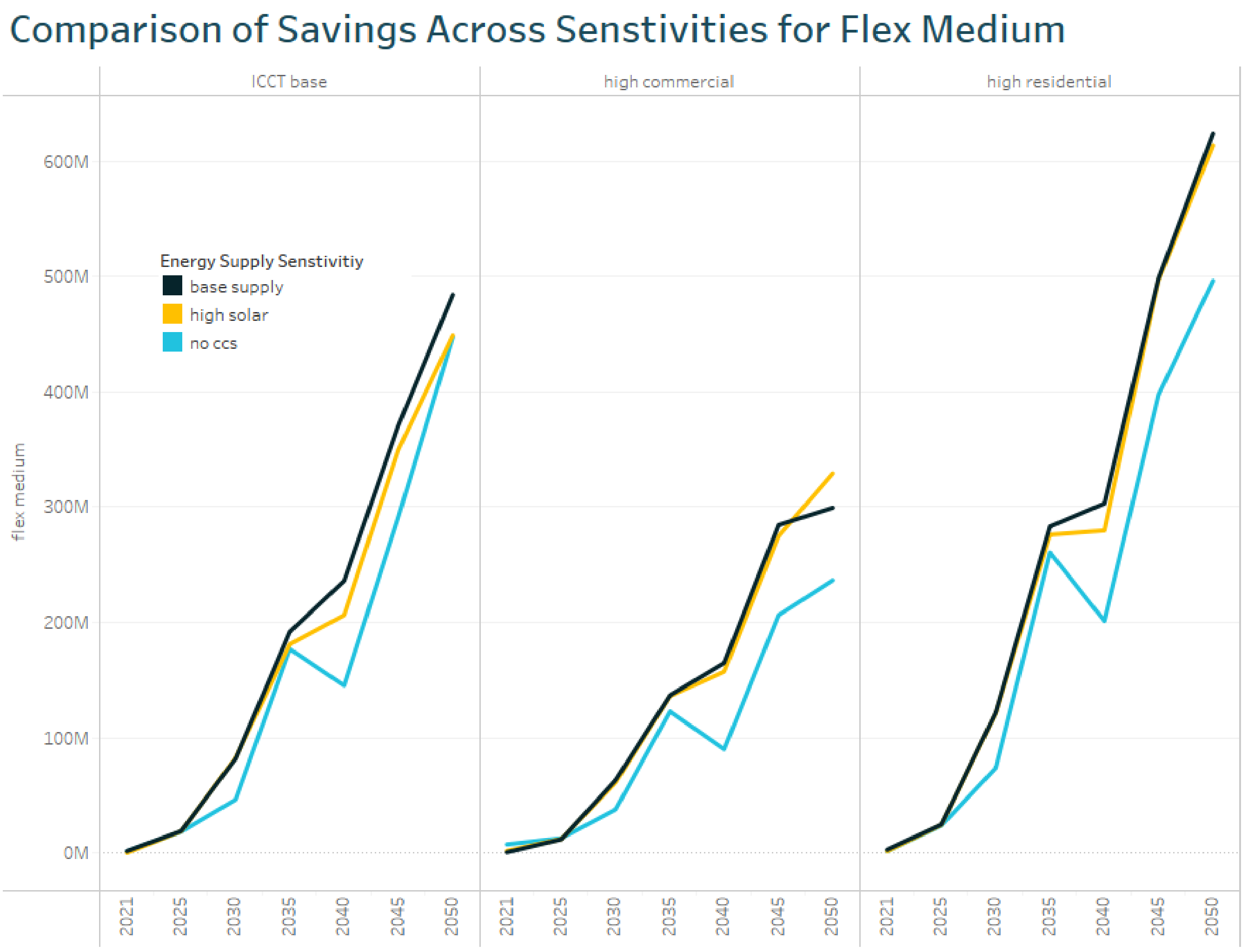
Electrolysis flexibility used across scenarios, storage replaced with flexible vehicle load

- MW of storage needed for peak load management reduced by availability of vehicle flexibility
- More significant shifting can be seen as scenarios increase vehicle flexibility and faster charging allows vehicles to maintain needed charge for following day
- Electrolysis only subtly dispatching against solar signal



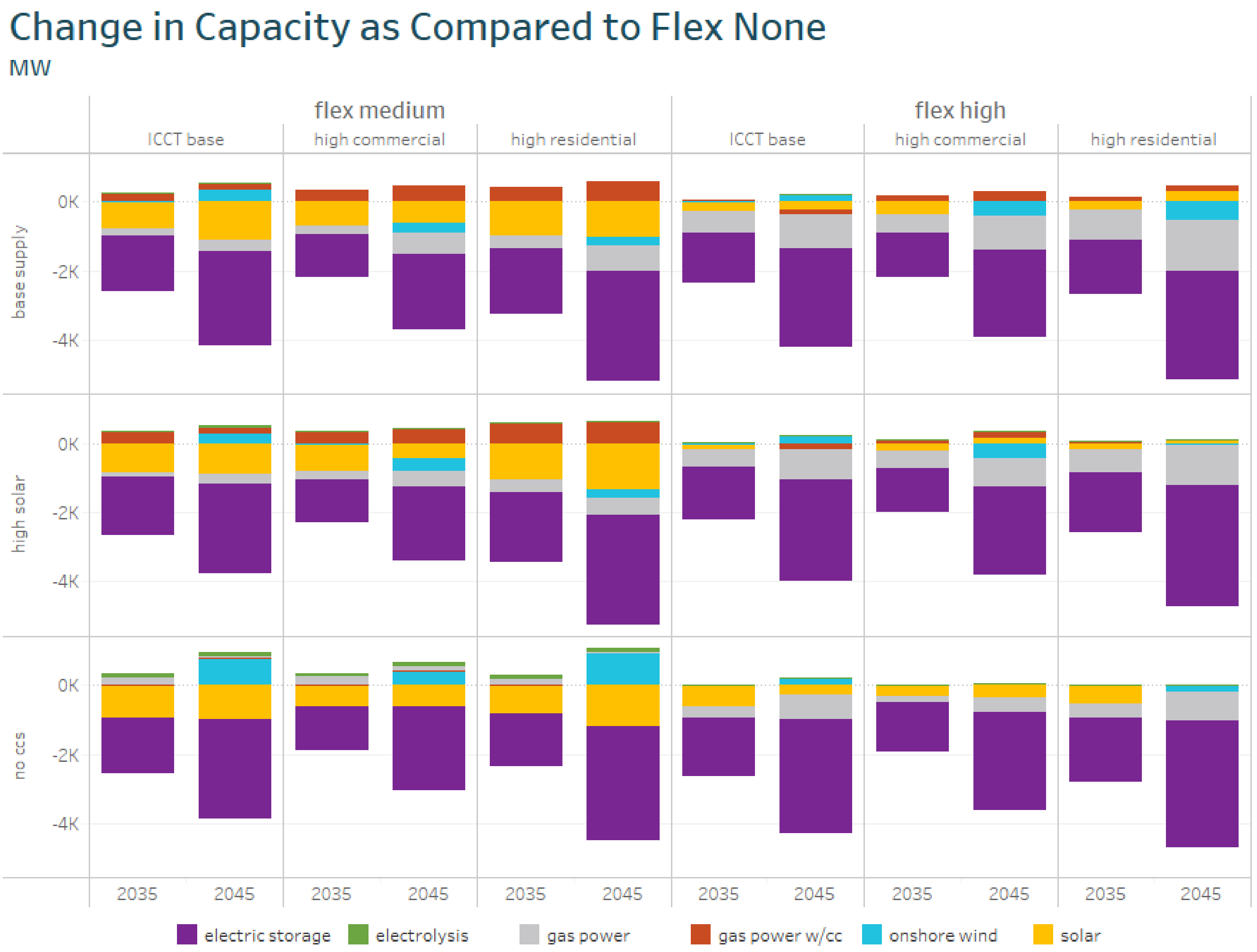
Sensitivity charts

- Sensitivities using high commercial charging patterns (Res 41%, Com 45%, HWY 14%) vs high residential charging patterns (Res 80%, Com 10%, HWY 10%) show that residential charging creates more value for the energy system
- This is true even with different mixes of solar, wind and availability of gas with CCS



Change in system build under different supply and charging location sensitivities

- Key capacity change in flexibility medium to flexibility high is that in flex medium, the model reduces investment in solar and storage but builds additional gas power with ccs (purple)
- There is also a tradeoff between building more wind and less solar
- Flexibility high reduces investments in gas peakers and storage, and builds similar levels of solar as in the no flexibility case. Showing that the longer duration flexibility enables more solar.



Greater vehicle flexibility lowers the cost of reducing emissions from the electricity sector

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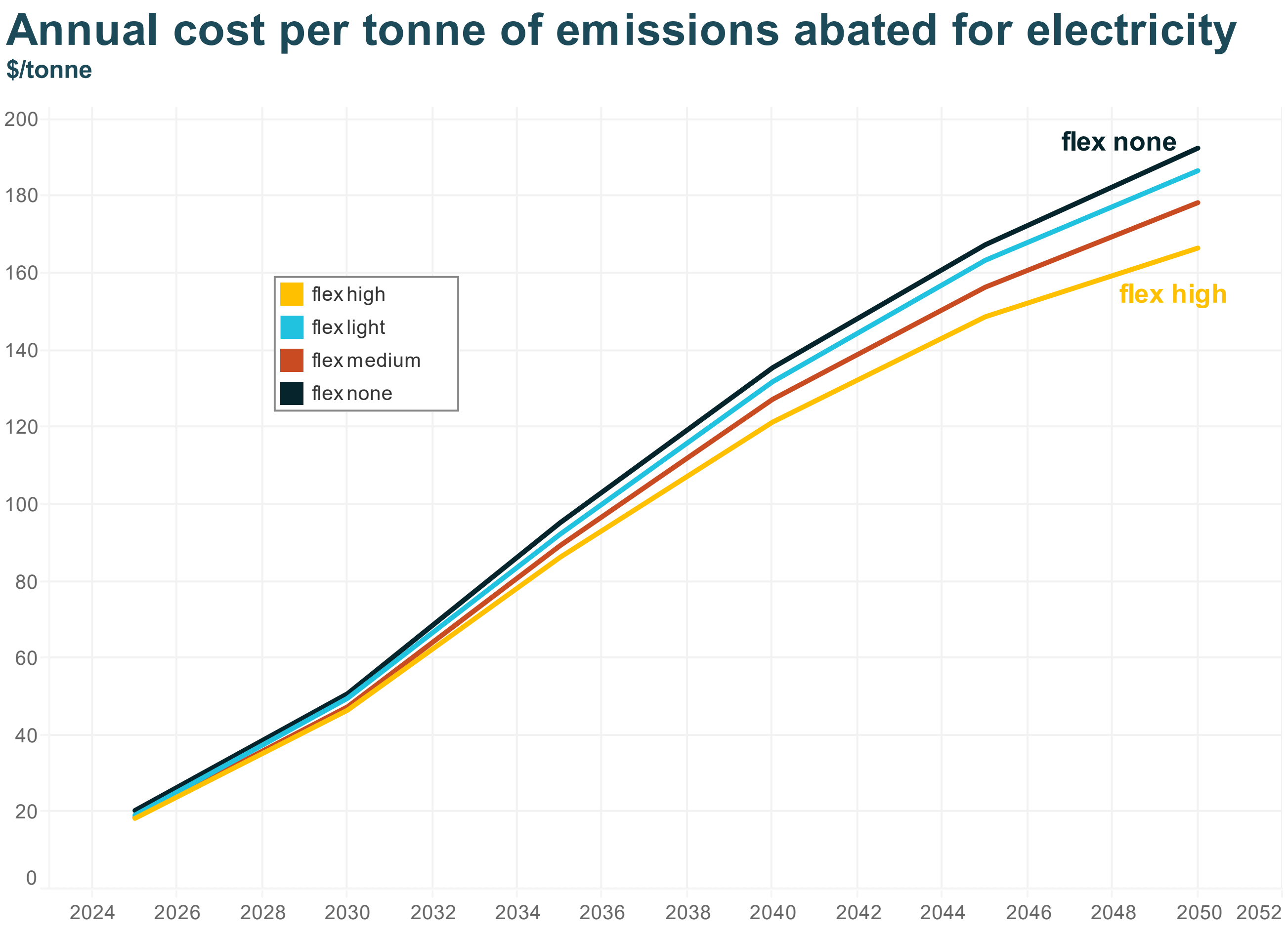
- Given the design of this analysis, with all scenarios constrained to hit the same electricity target, higher levels of vehicle flexibility do not impact emission reductions.
- The savings from higher levels of vehicle flexibility translates into lower abatement costs for the electricity sector.
  - The flex high scenario reduces the annual dollars per tonne cost of reducing electricity emissions by roughly 10% in each year of the analysis.



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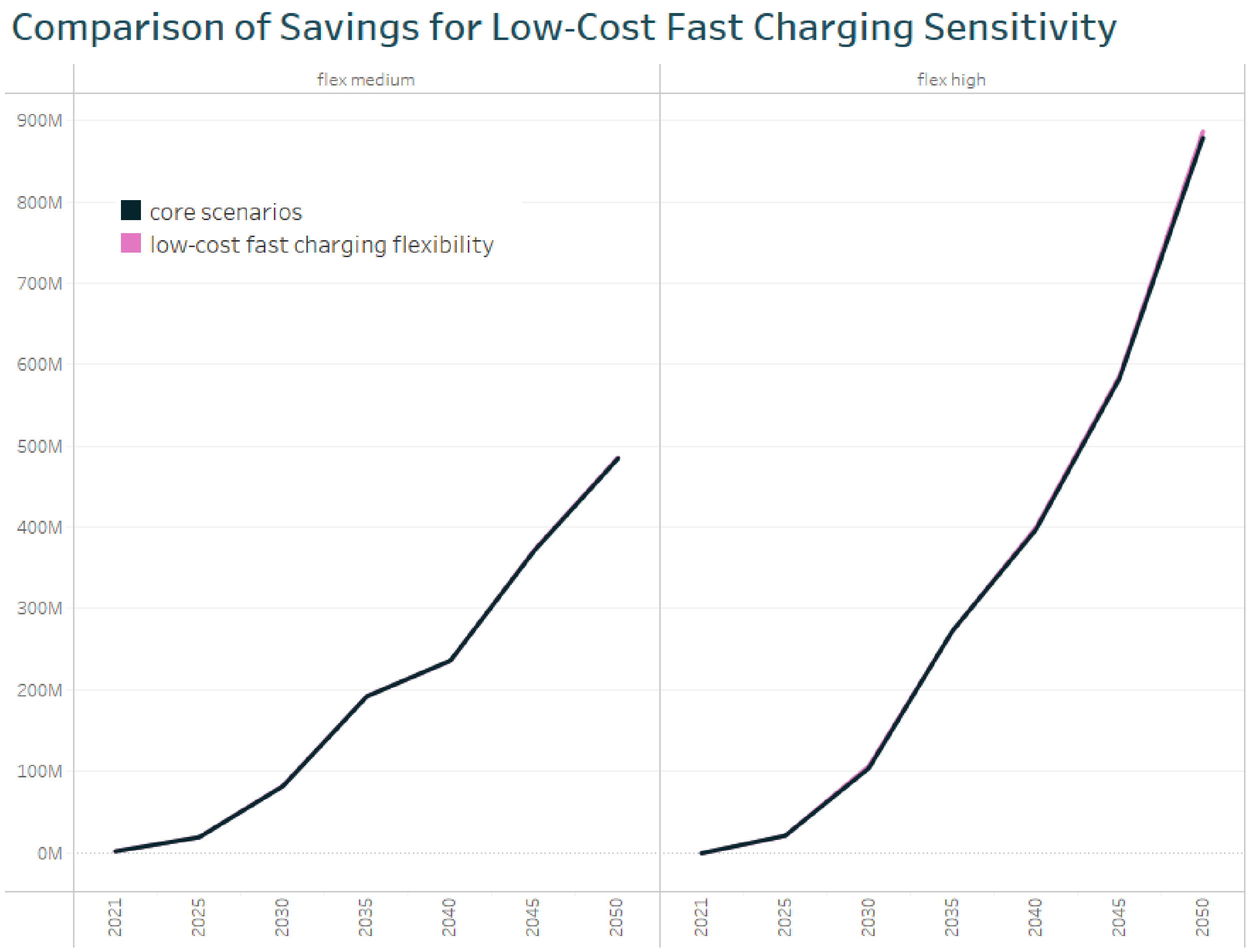
Appendix: Additional Chart Details

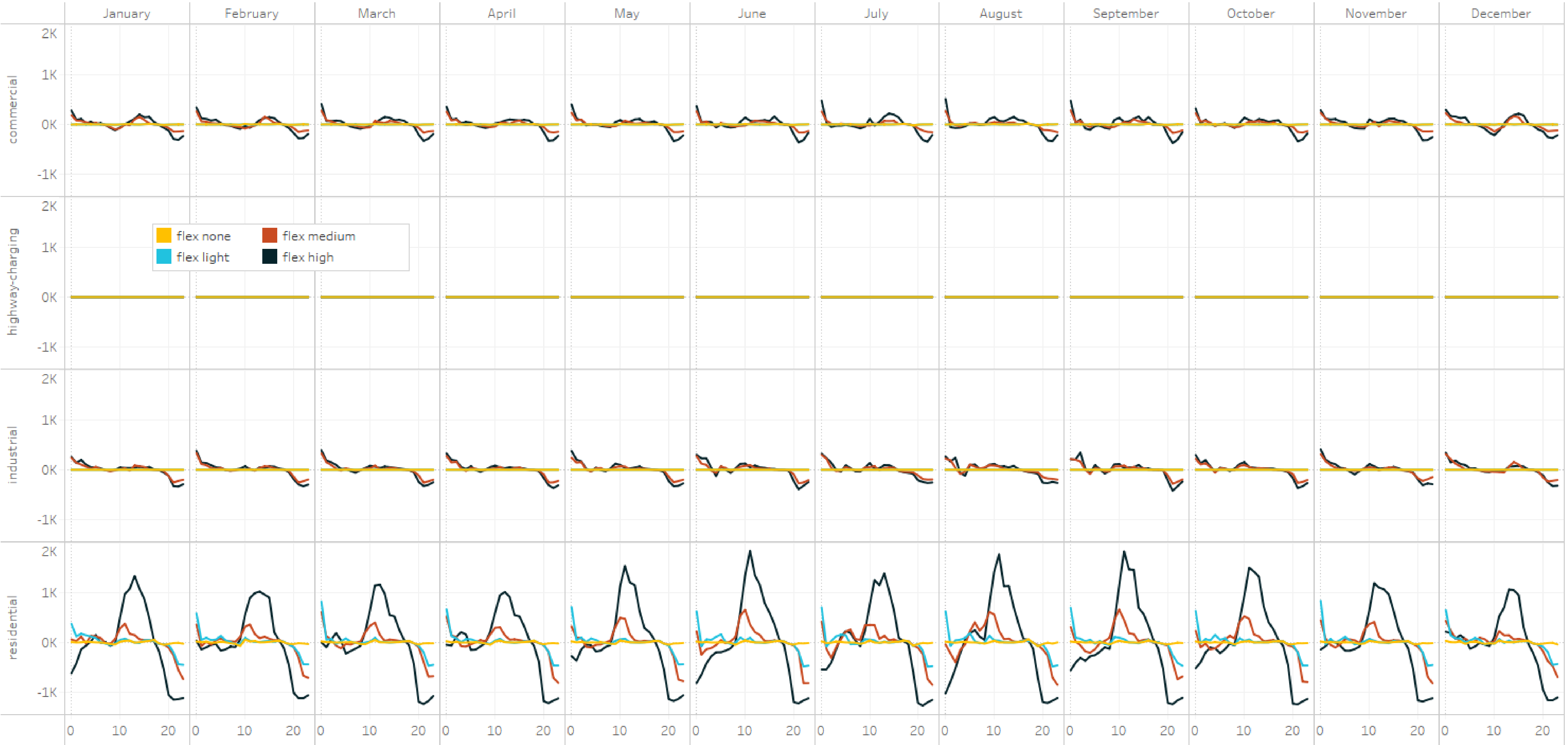
Comparison of system costs with low-cost highway fast-charging

- The core scenarios include a higher customer cost of FCDC charging for both LDV and MHDV
- The sensitivity analysis reducing customer charging cost for FCDC has minimal impact on overall value
  - In most years, the impact is less than 0.5% of total savings
  - For high flexibility, by 2050 savings are ~2% higher

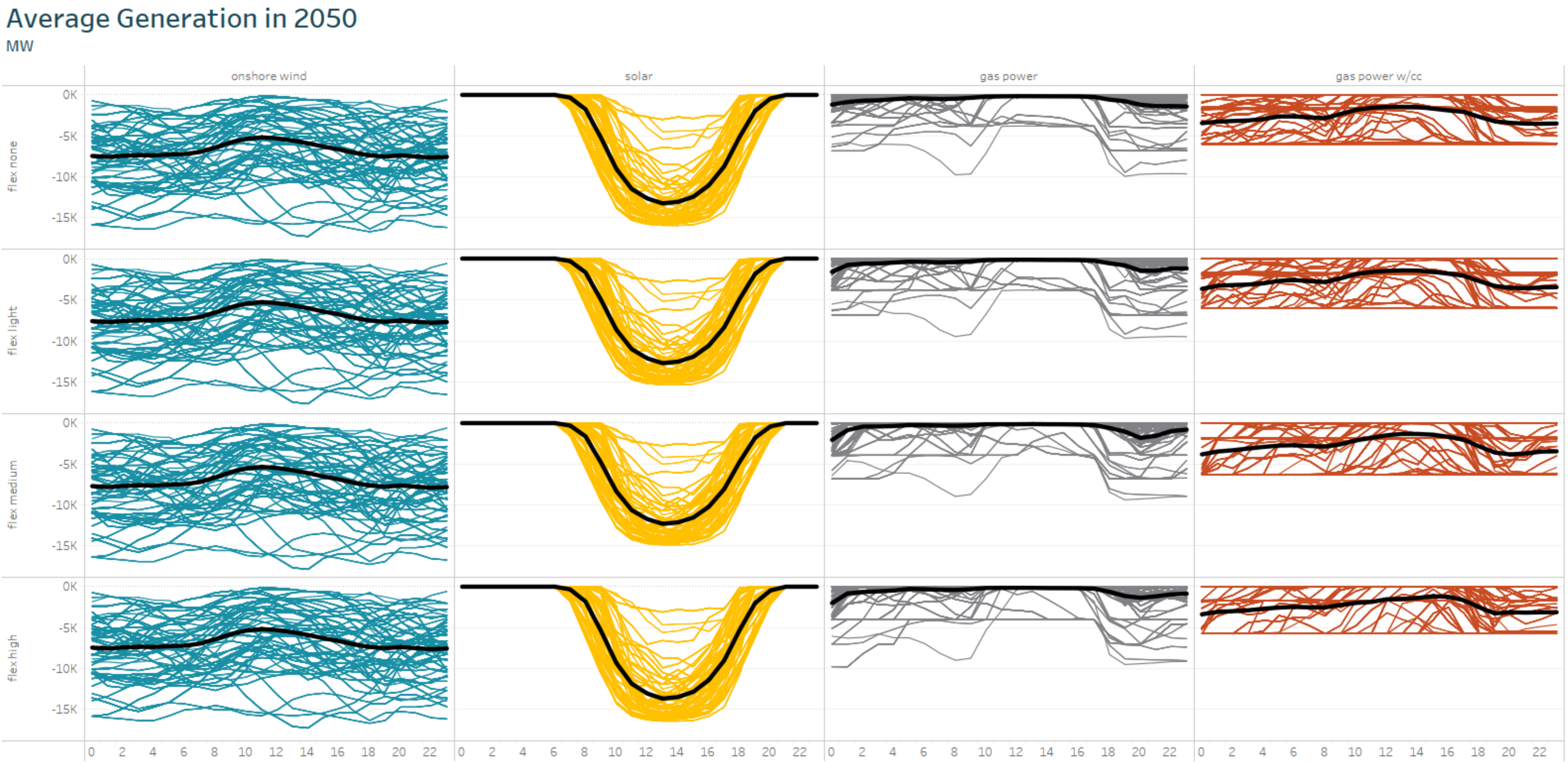


Flexible Vehicle Load Averages by Month in 2050

MW



Generation resource behavior in decarbonized modeled system



THANK YOU

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