Mobile Carbon Dioxide Removal: A Baseline Cost Estimate and Testing Protocol

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Acknowledgements

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United States Environmental Protection Agency

Rackham Graduate School
University of Michigan

Vehicles are a significant source of emissions

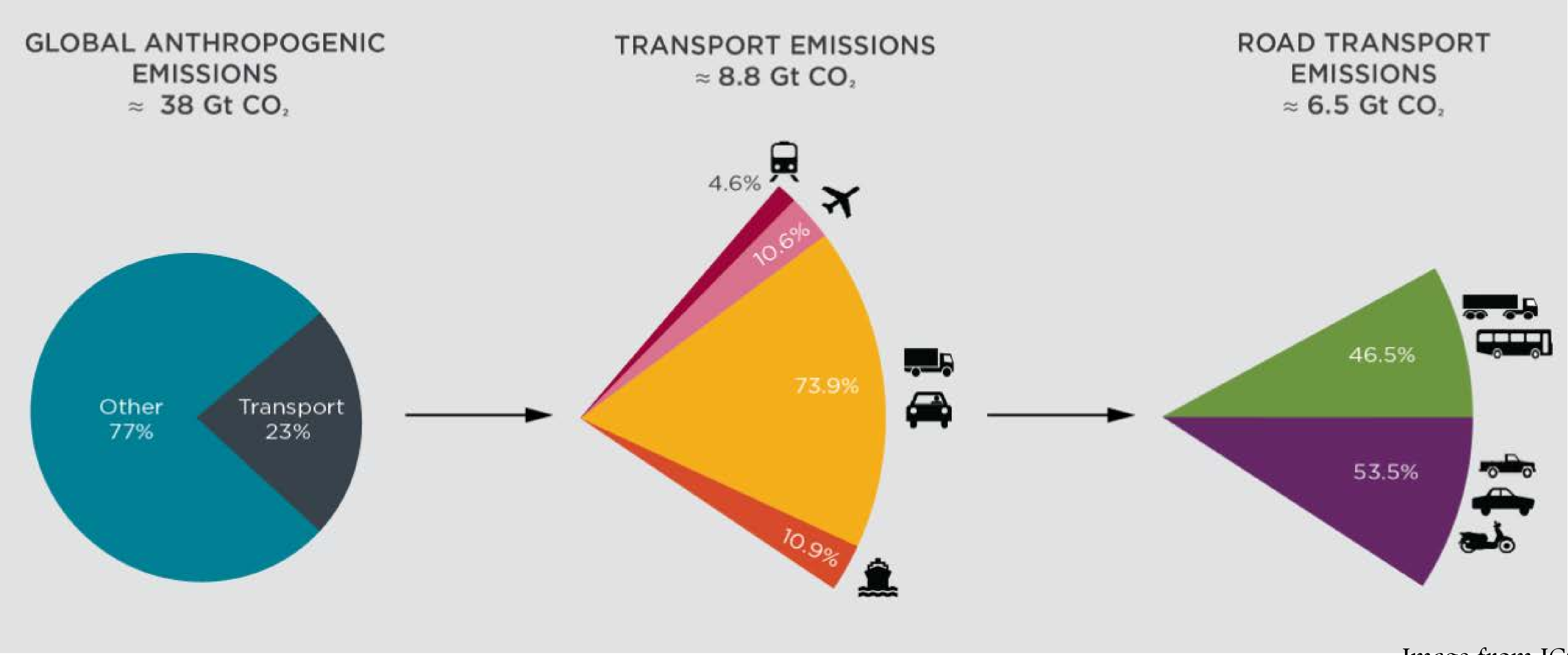


Image from ICCT

Transportation is the highest emitting sector through 2040

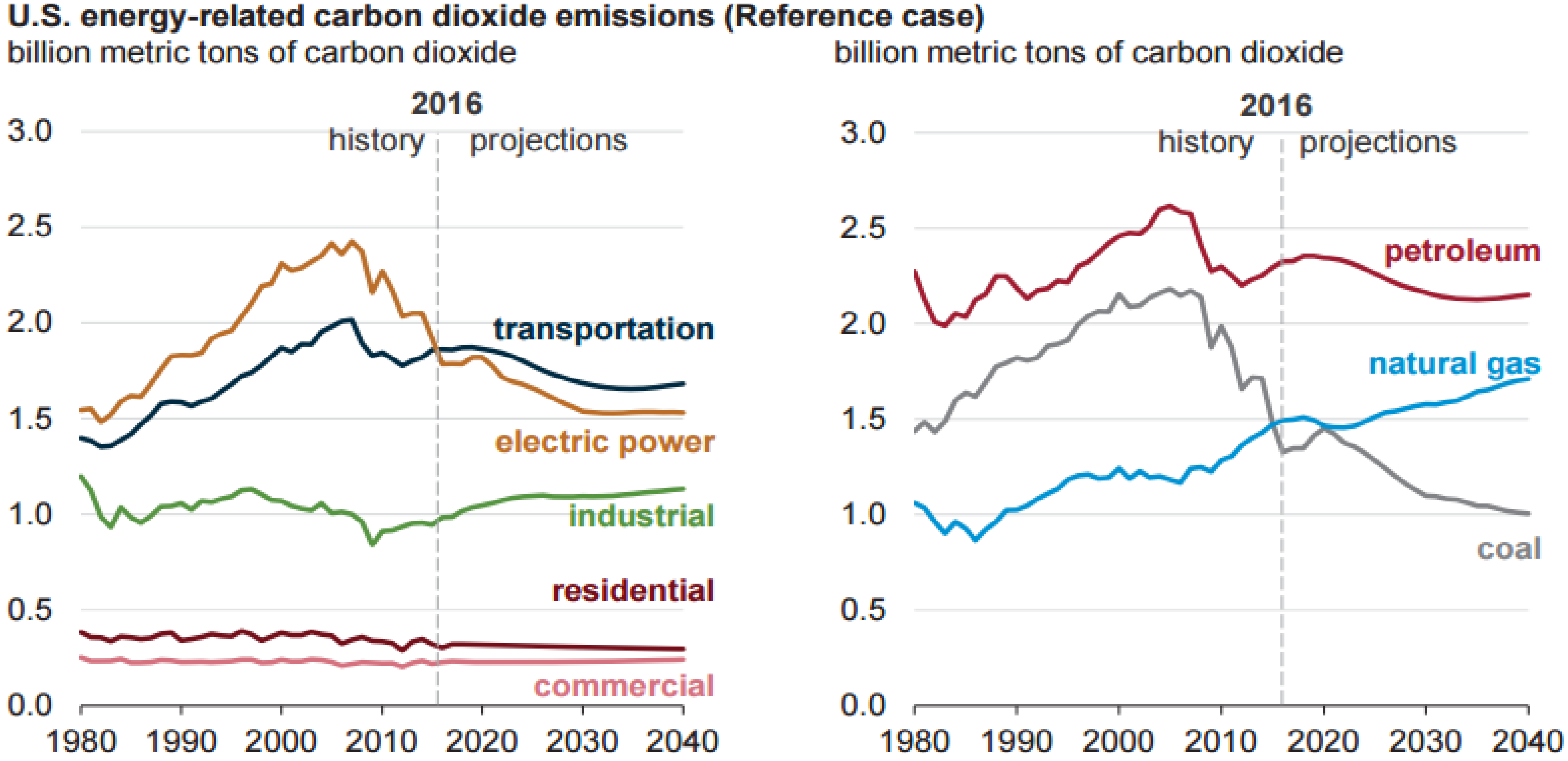
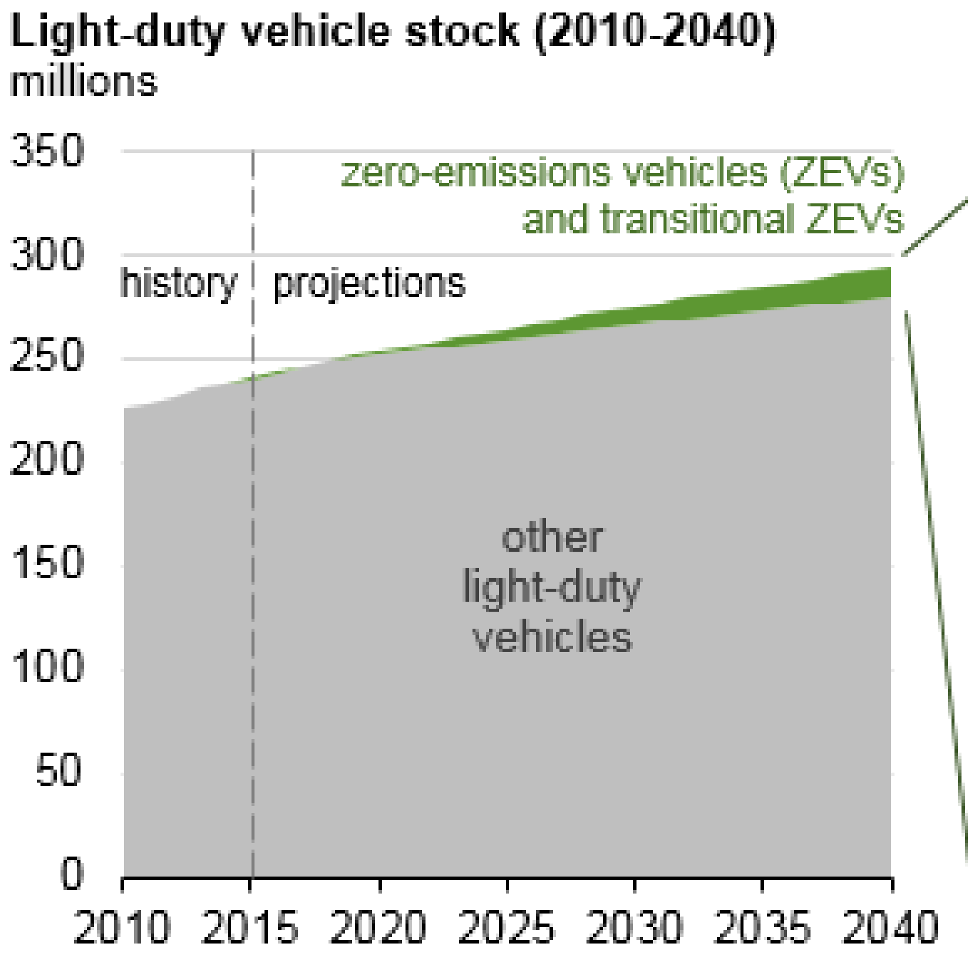
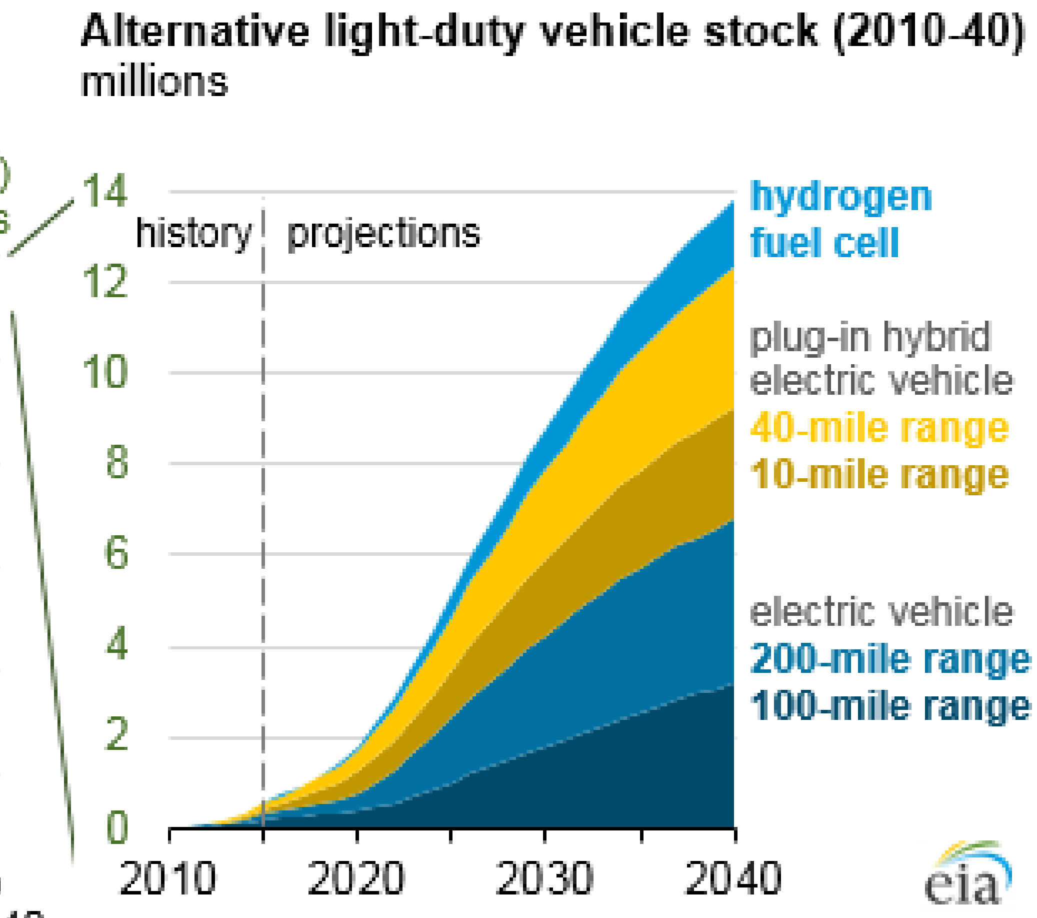


Image from US EIA

Carbon-fueled vehicles retain the highest market share through 2040

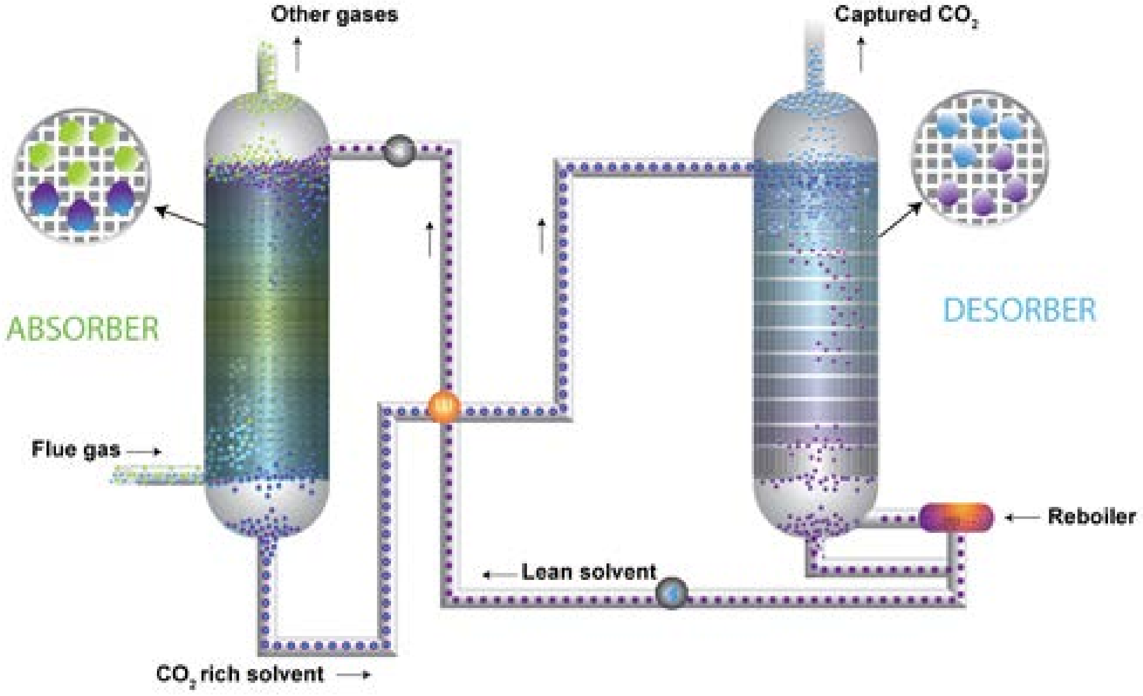




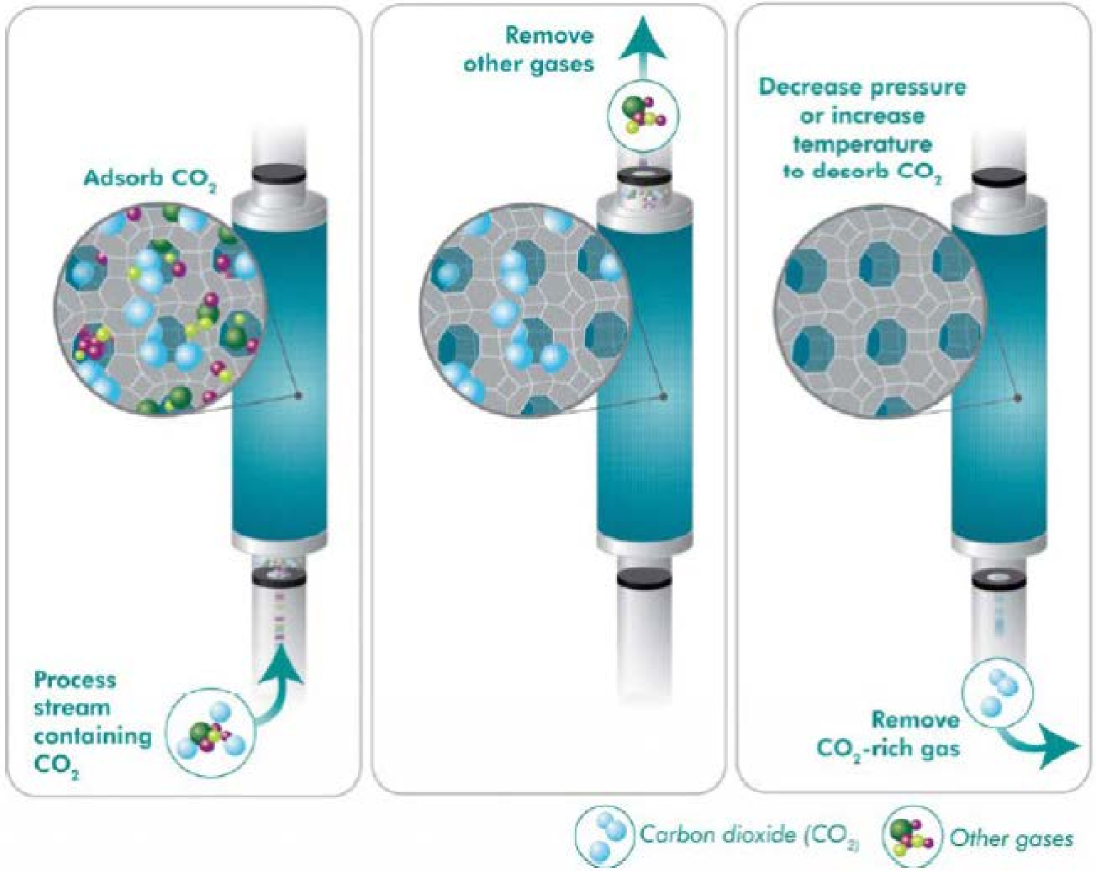
Climate stabilization targets cannot be achieved without carbon dioxide removal from mobile emission sources!

But how do we accomplish this?

Approaches to carbon capture from stationary sources



Amine Solvents



Conventional or Novel Adsorbents (zeolites, activated carbons, MOFs)

Image from CO2CRC

Direct Air Capture is expensive

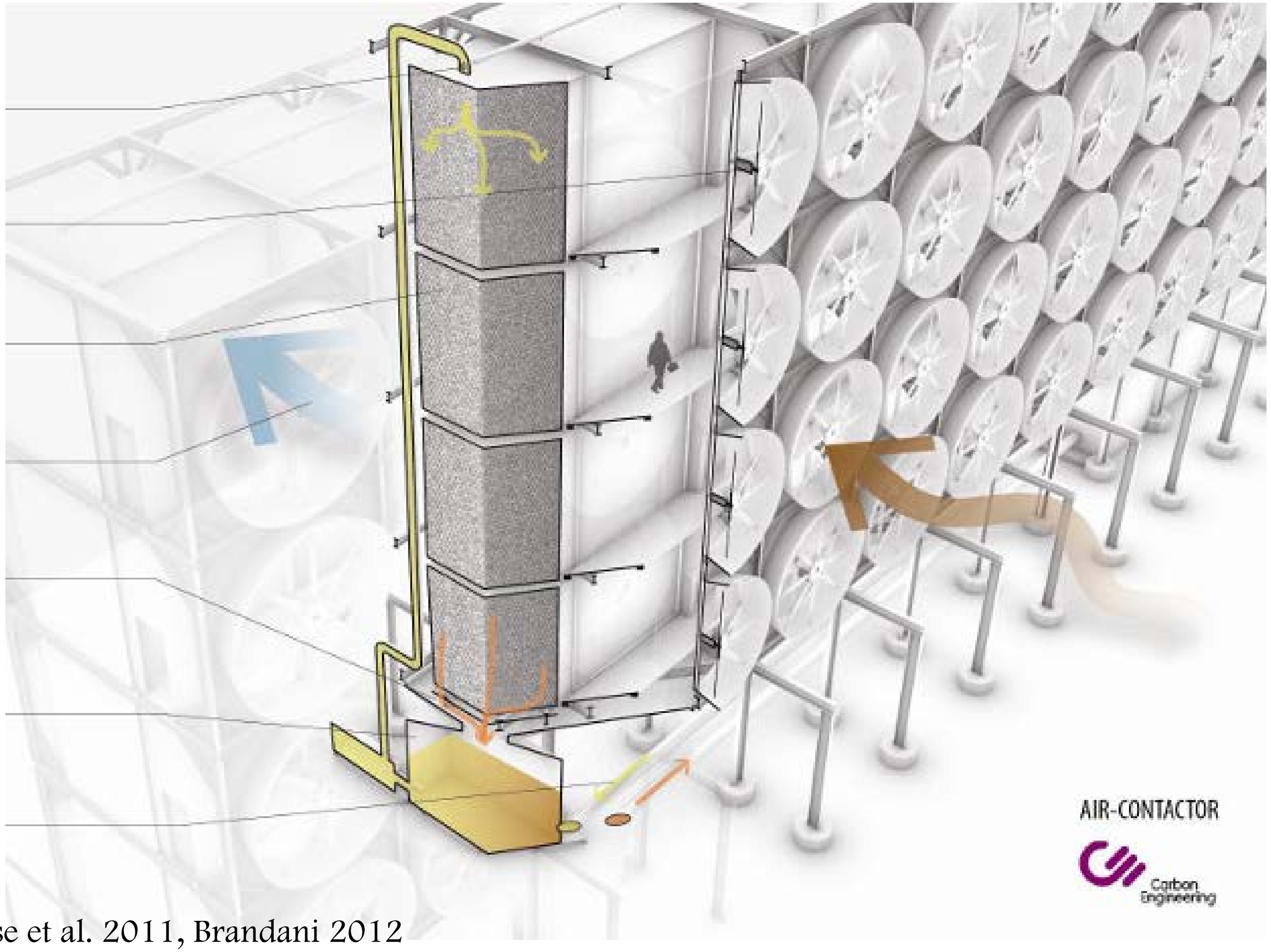


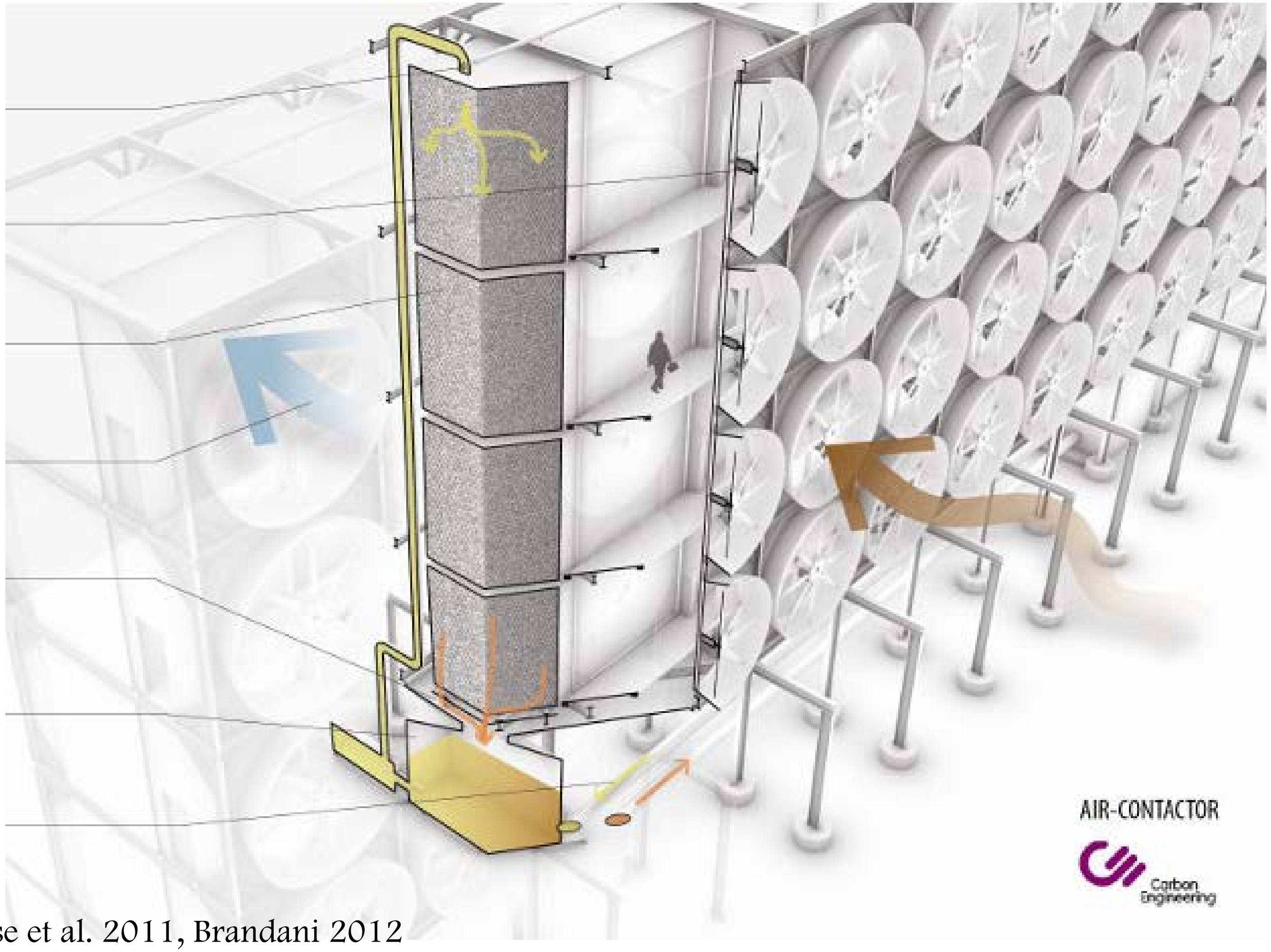
Image from Carbon Engineering; References: Socolow et al. 2011, House et al. 2011, Brandani 2012

Direct Air Capture is expensive

Expected cost:

> $600/t$CO_2$

- **10 times** the cost of capture from power plants



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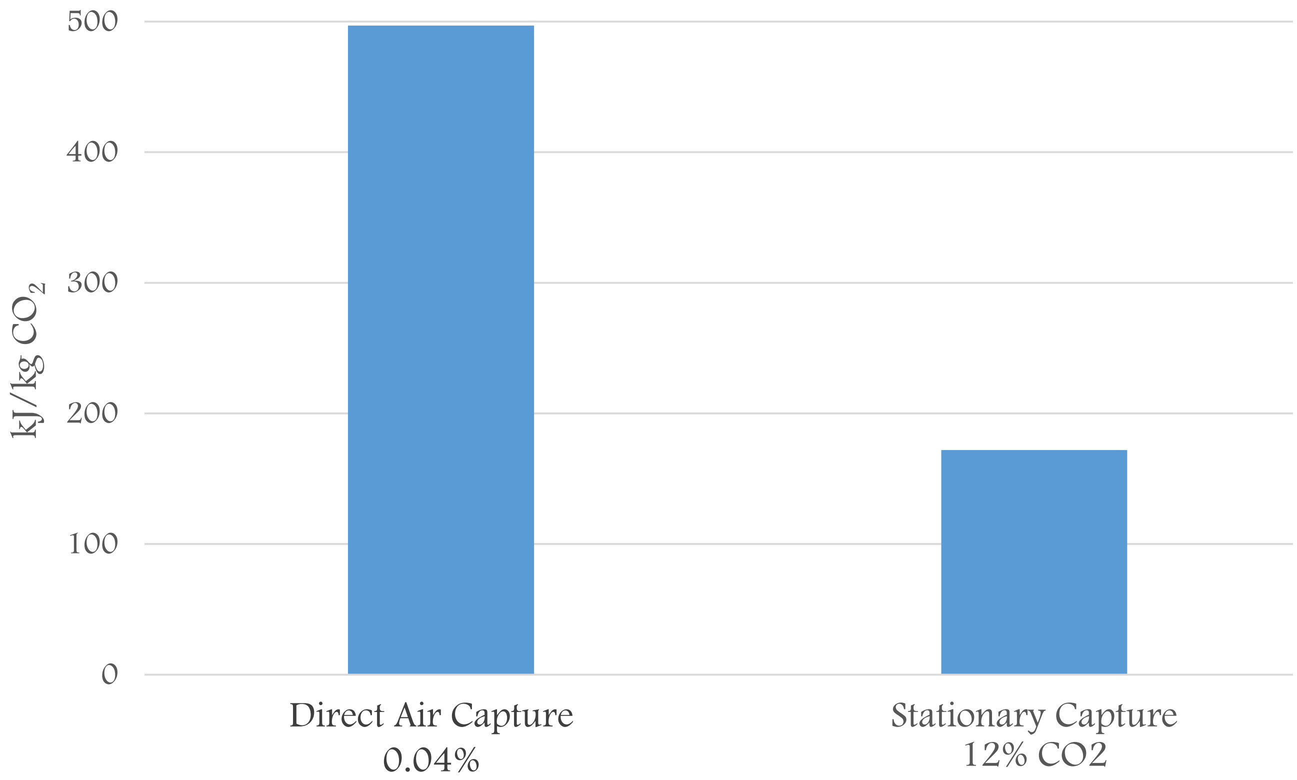
Minimum work to separate increases as CO_2 concentration decreases



$$w_{min,100\%} = -\frac{RT}{y_A M_A}\left[y_A \ln(y_A) + (1 - y_A)\ln(1 - y_A)\right]$$

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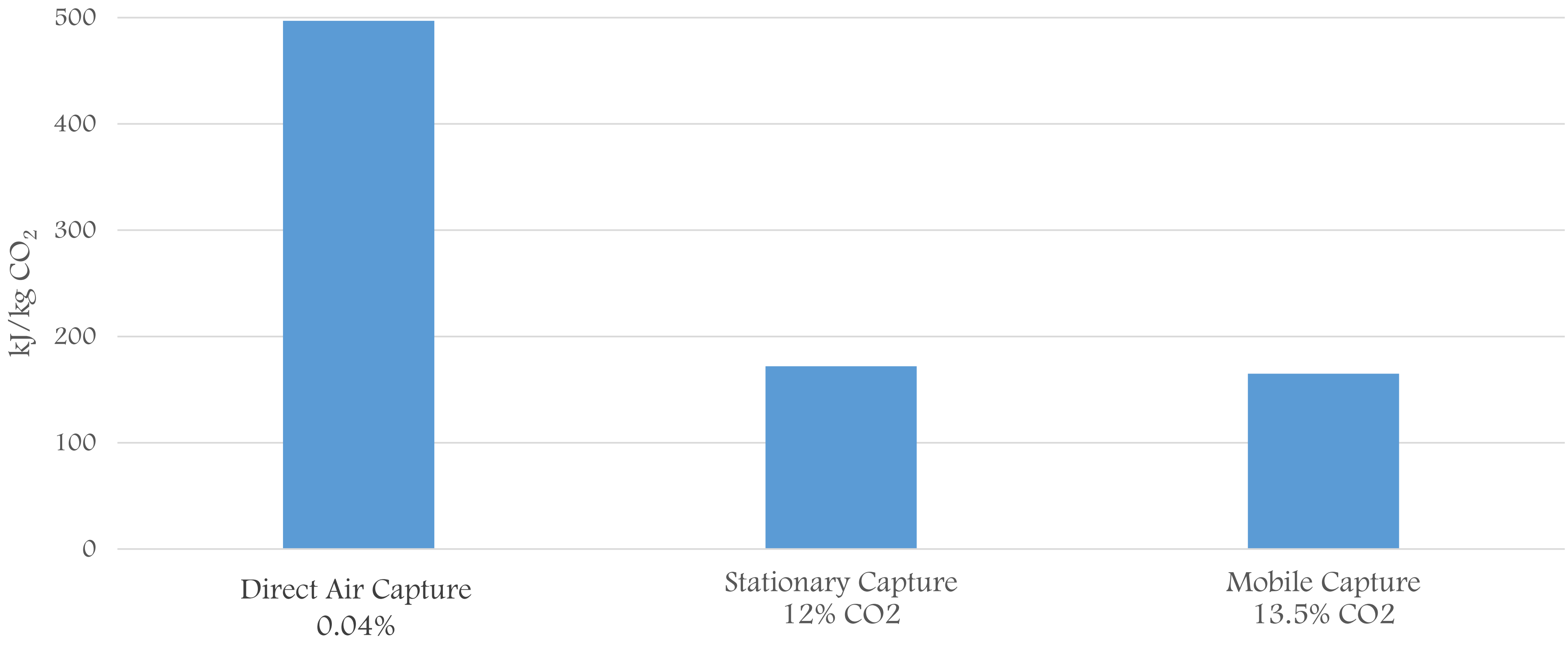

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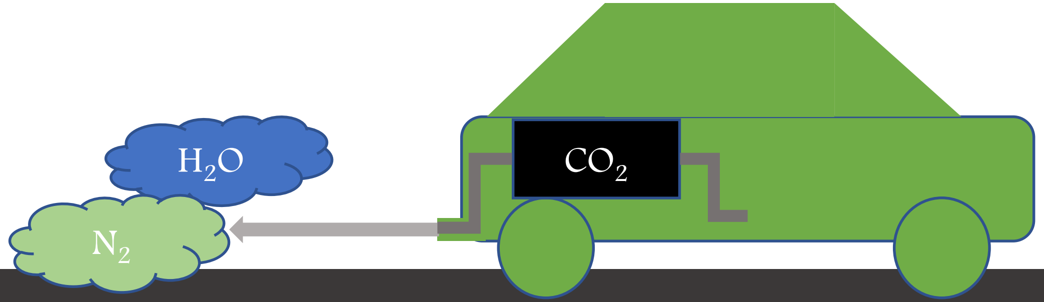
So let's consider a mobile carbon capture system
modeled along the lines of a stationary capture system…

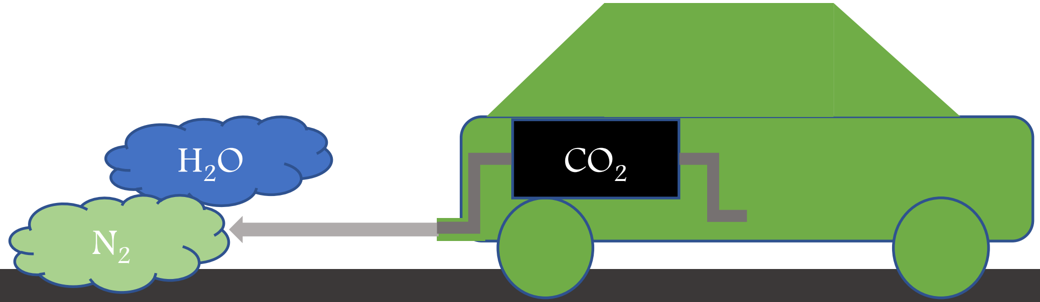
Carbon Dioxide Removal from Mobile Emission Sources



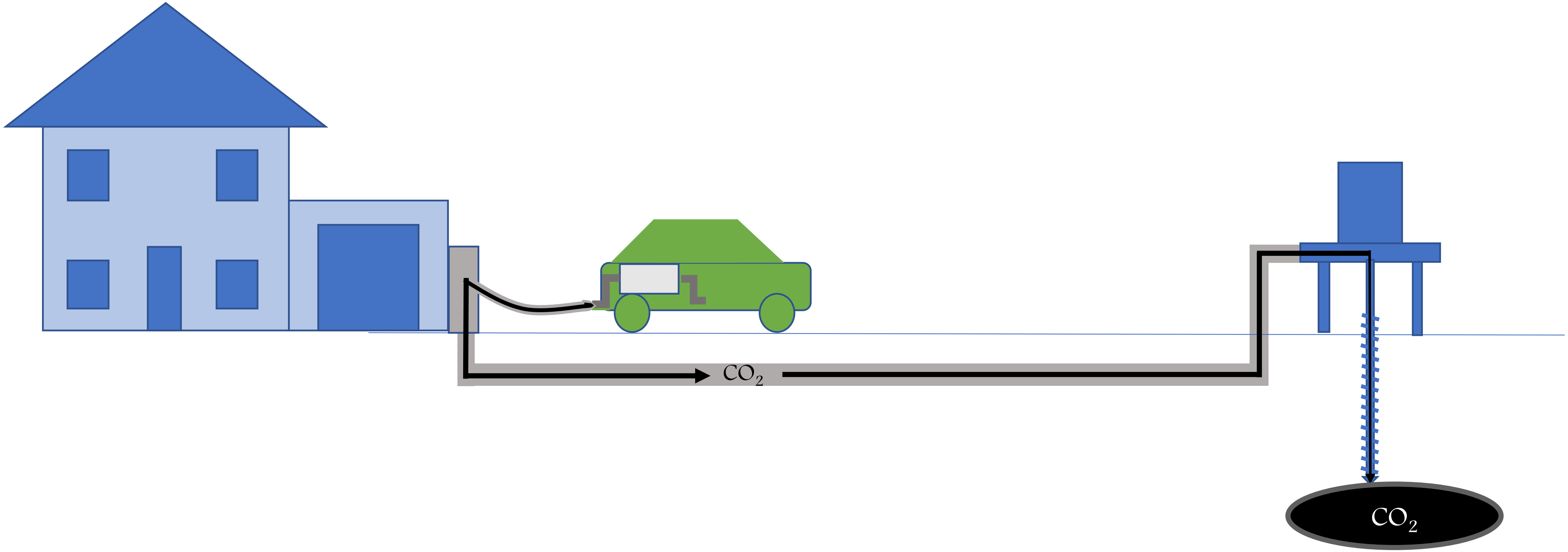
Carbon Dioxide Removal from Mobile Emission Sources

To capture the CO_2 emissions from 300 miles of driving in a light-duty vehicle, we need 650 kg of adsorbent with 20 wt% CO_2 capacity.

Mass requirements can be significantly decreased by changing several key conditions.



How do we offload CO_2 once it's captured?

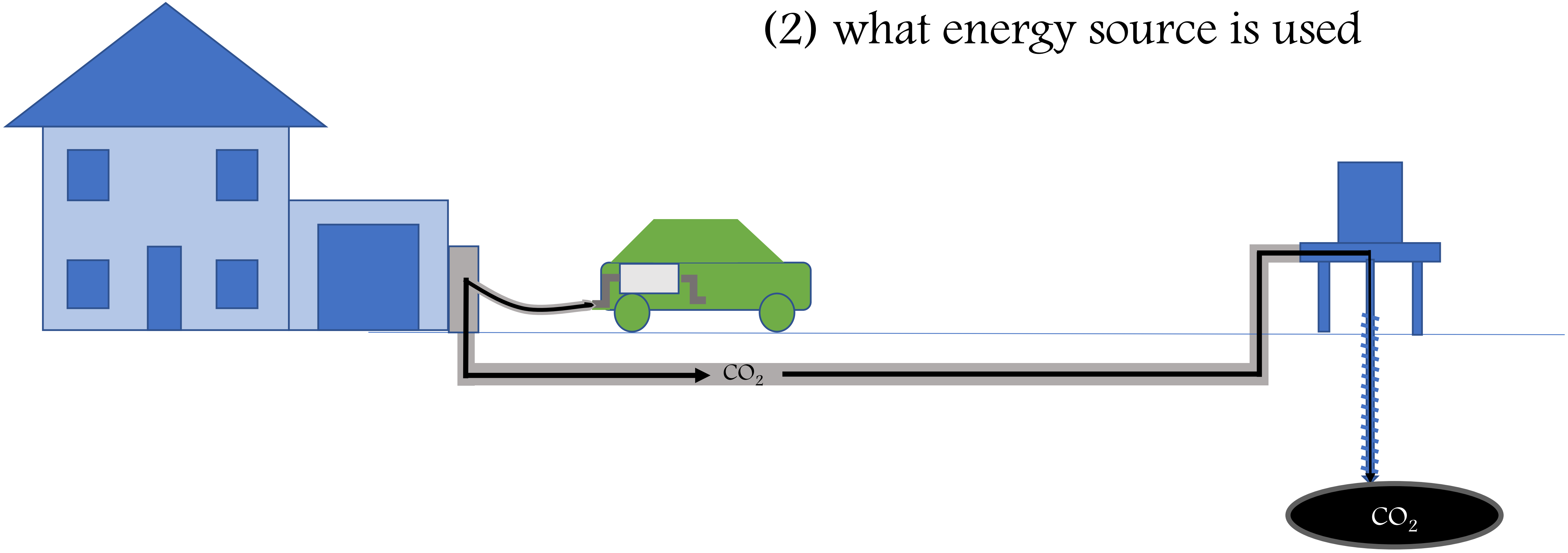


How do we offload CO_2 once it's captured?

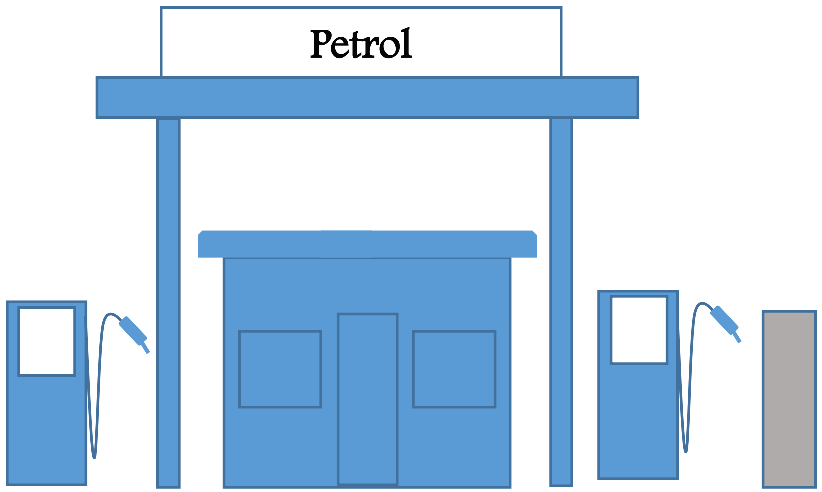
Must decide:

(1) where and when offloading occurs

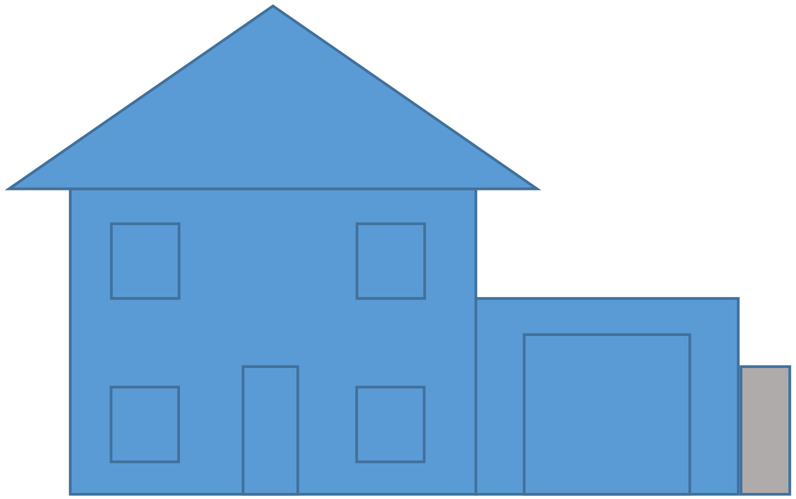
(2) what energy source is used



Where and when to offload CO_2?

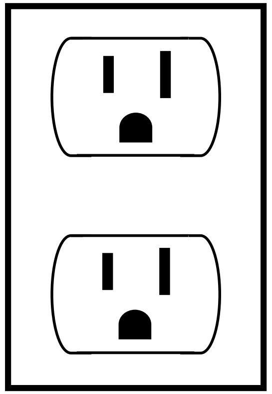


Regeneration at Gas Station
(travel distance = **300 mi**)



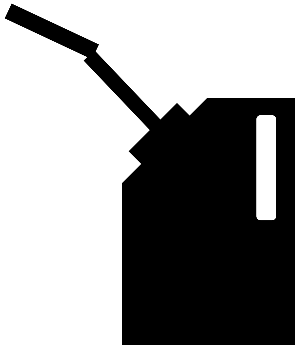
Regeneration at Home
(travel distance = **30 mi**)

What energy source to use?



Power Plant or Renewables

$0.10/kWh



Internal Combustion Engine

$3/gallon

Cost categories and relevant assumptions

Weight/fuel penalty

Separation and compression

Capital costs

Transportation and storage

Cost categories and relevant assumptions

Weight/fuel penalty	target fuel economy	45 mpg
	weight → miles per gallon	7% ↓ in mpg per 10% ↑ in mass
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Separation and compression	η_{II} separation/compression	0.40 / 0.85
	carbon intensity of electricity	0.5 kg/ kWh
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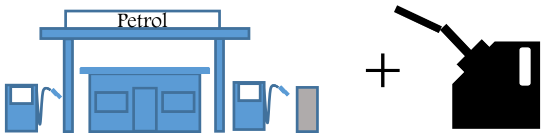
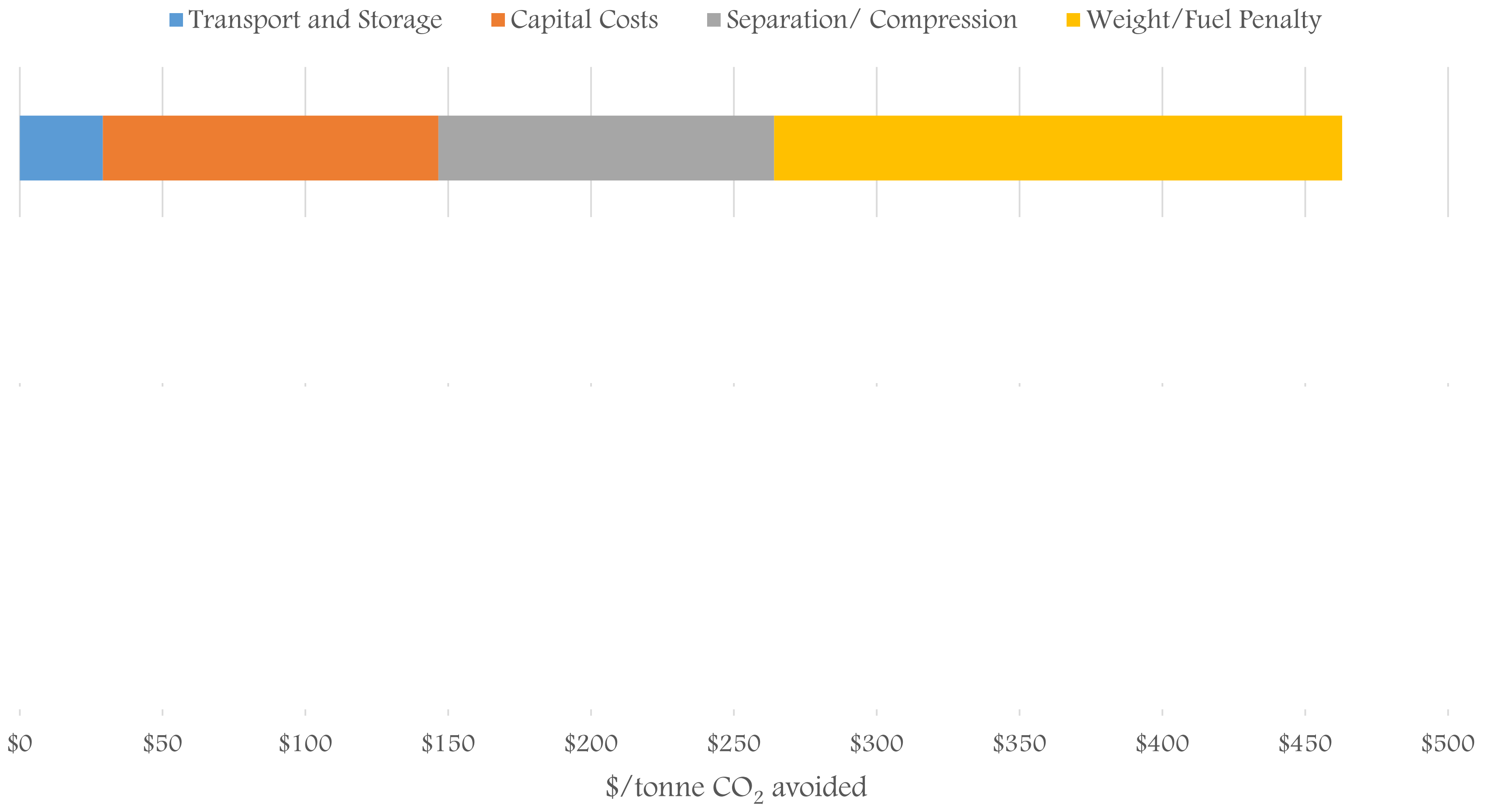
	carbon intensity of electricity	0.5 kg/ kWh
Capital costs	100%	separation and compression costs
Transportation and storage	pipeline transport	$2/tonne
	distance	100 km
	CO_2 emissions	0.005 kg/tonne-km
	storage	$13/tonne

Cost estimate for mobile capture scenarios

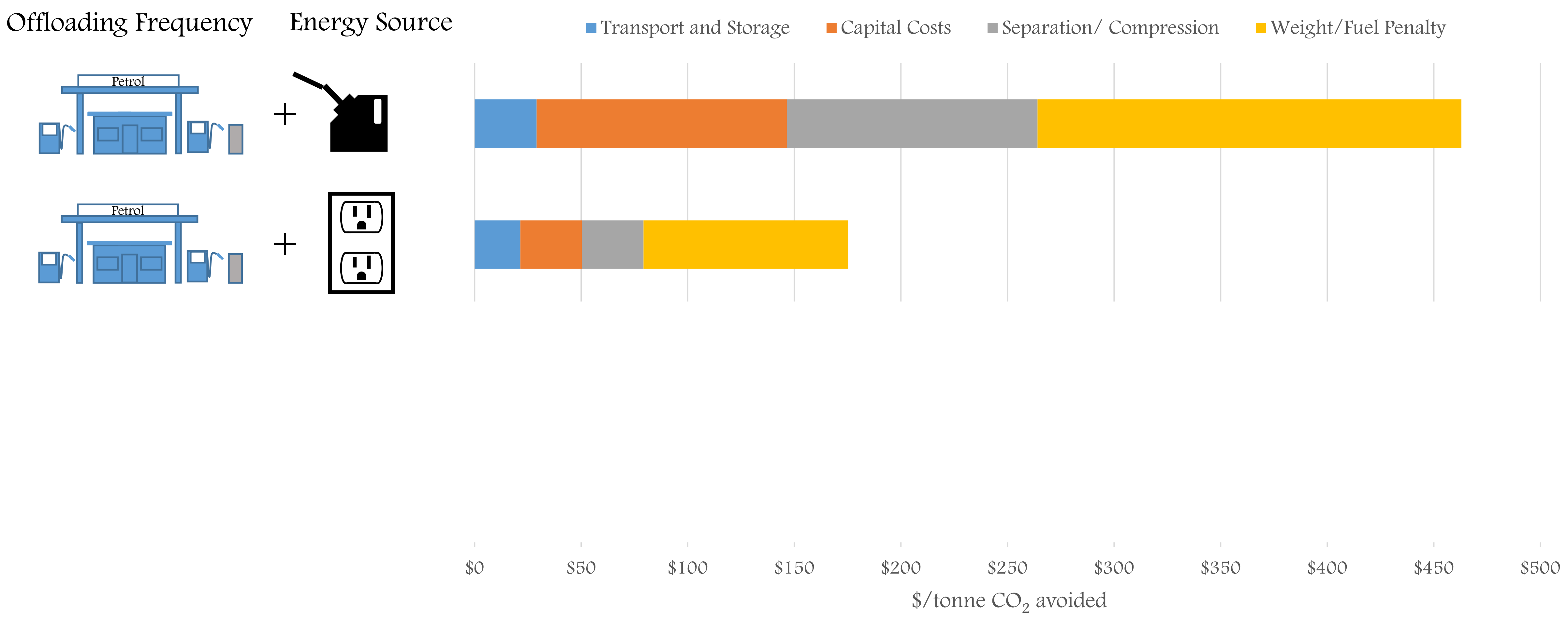
Offloading Frequency

Energy Source





Cost estimate for mobile capture scenarios



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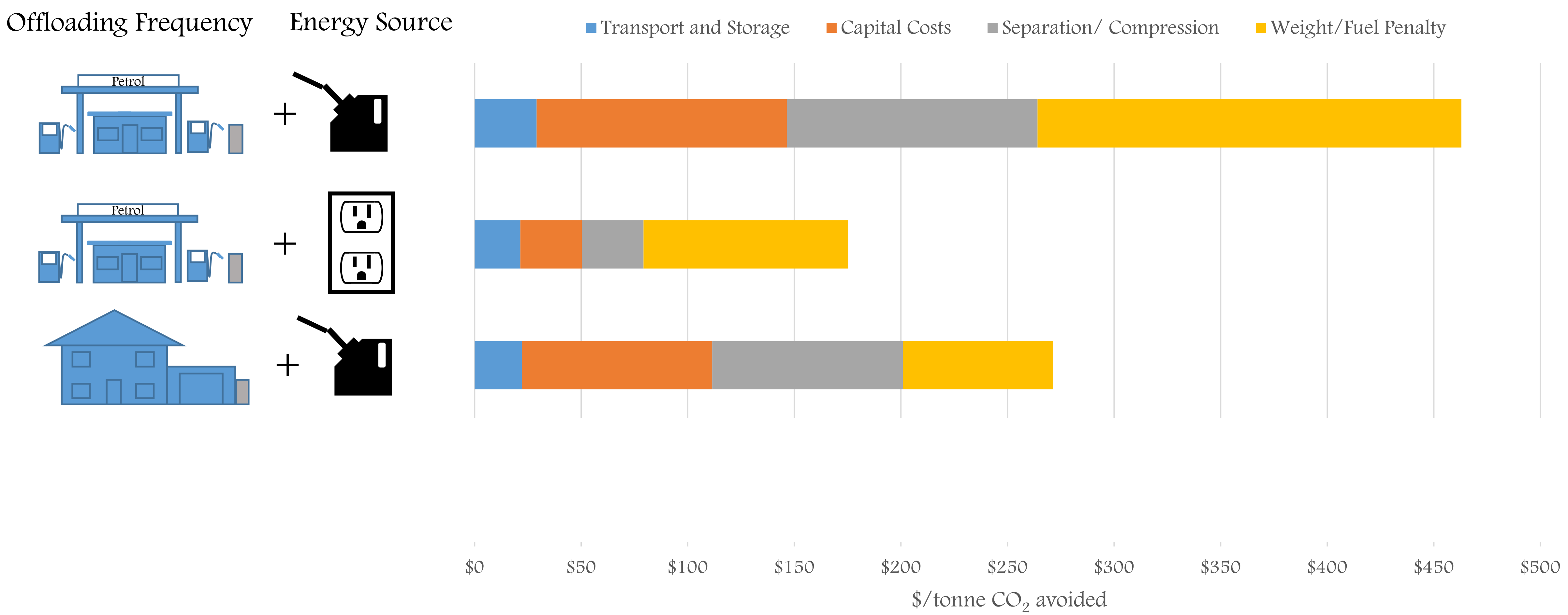

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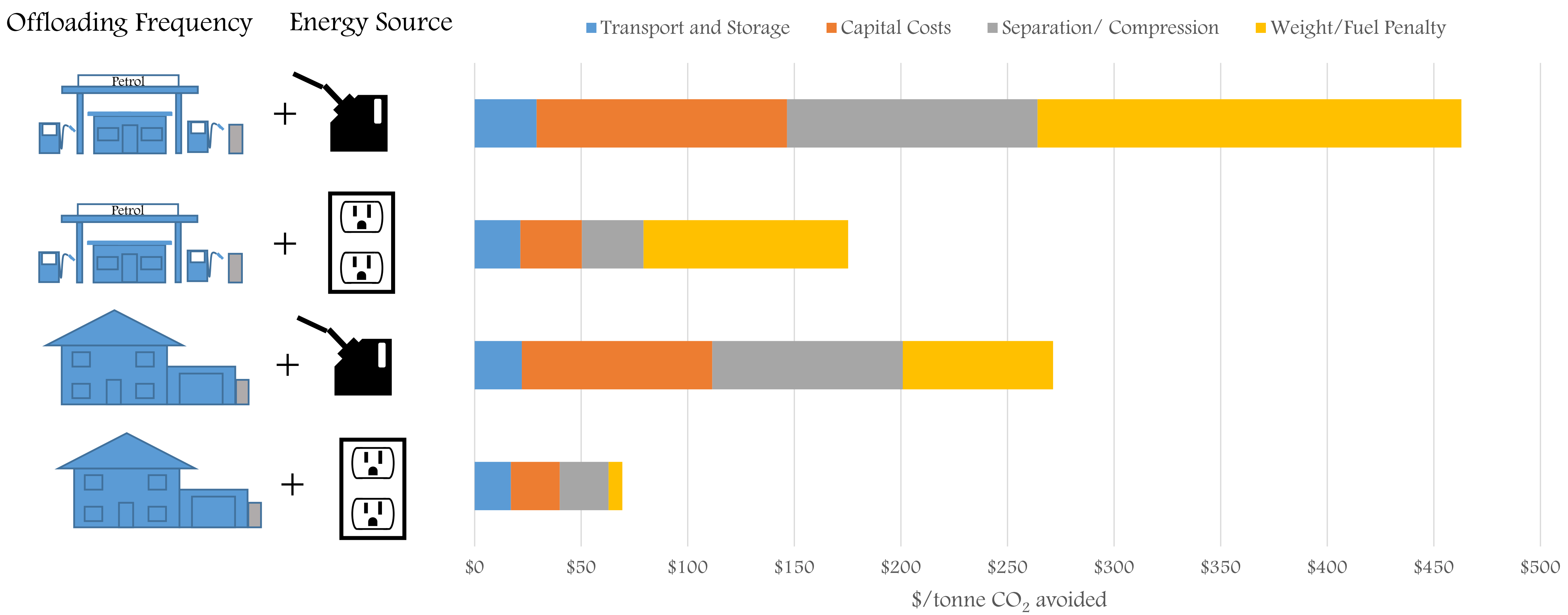

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Average car emissions:	6 tons CO_2 per year
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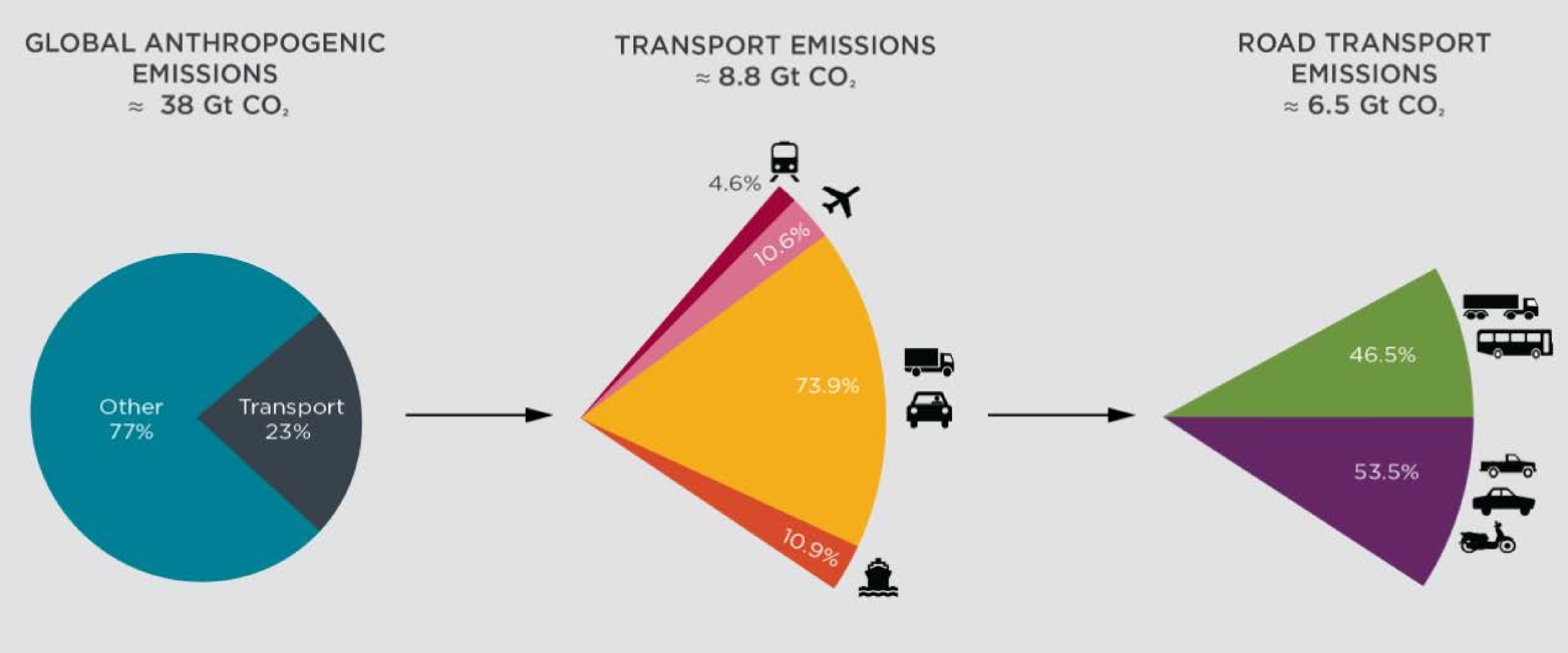
Almost equal share of emissions from heavy duty and light duty vehicles



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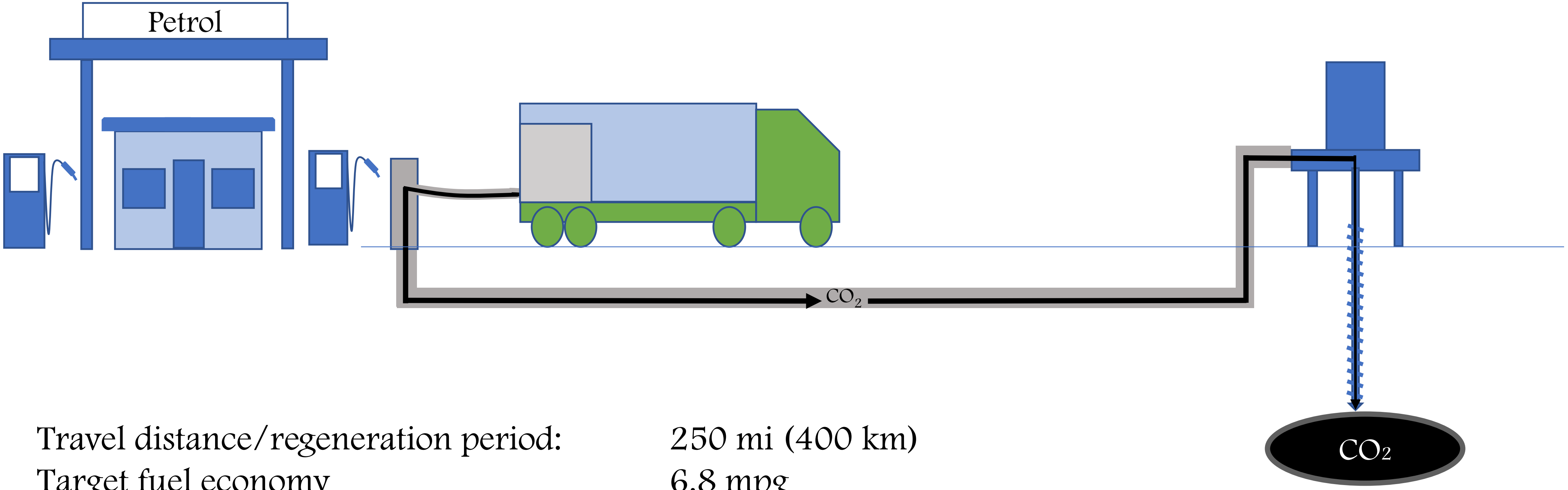
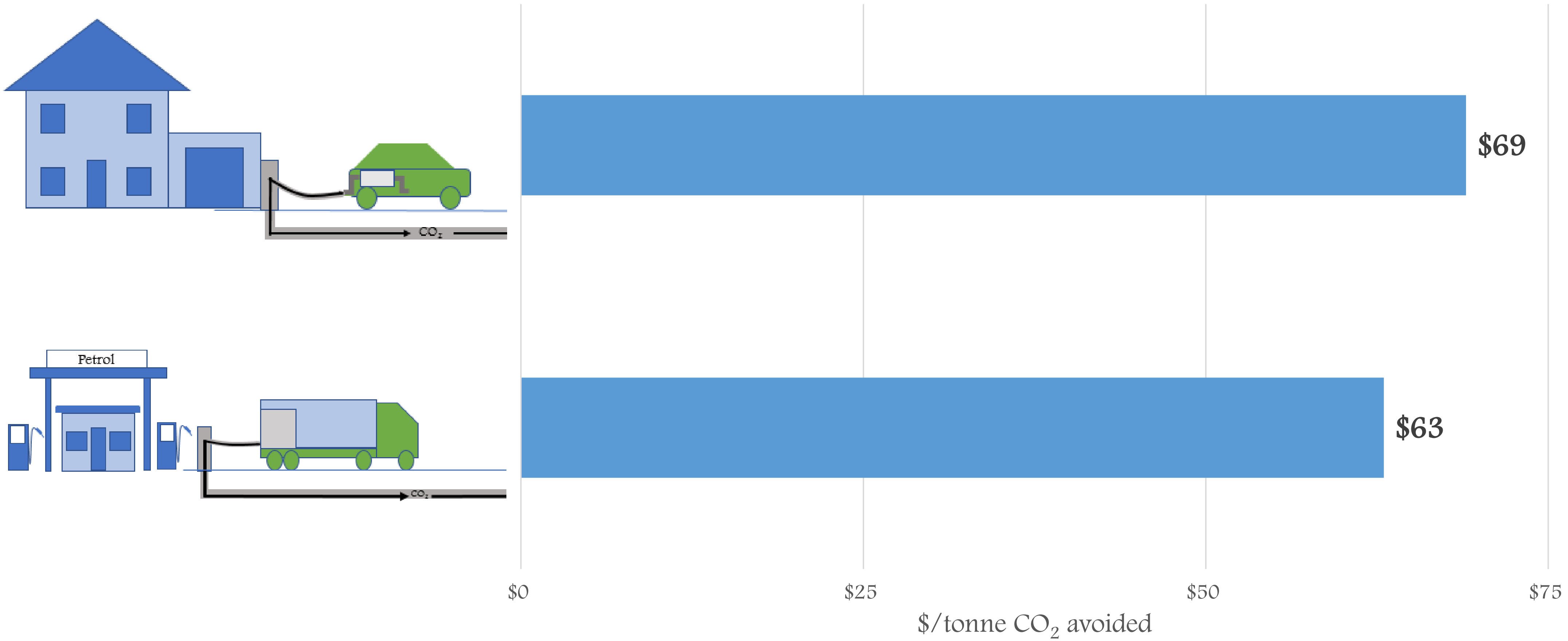


Travel distance/regeneration period: 250 mi (400 km)
Target fuel economy 6.8 mpg

CO_2 capture from heavy duty vehicles is comparable with light duty best case scenario



What does this mean for you?

Freight trucking emissions:	530 M tonnes of CO_2 per year
Price of CO_2 abatement:	$63/ton
Average ton-miles of US freight:	2.6 B (or 8 ton-miles per person)
New annual shipping premium:	

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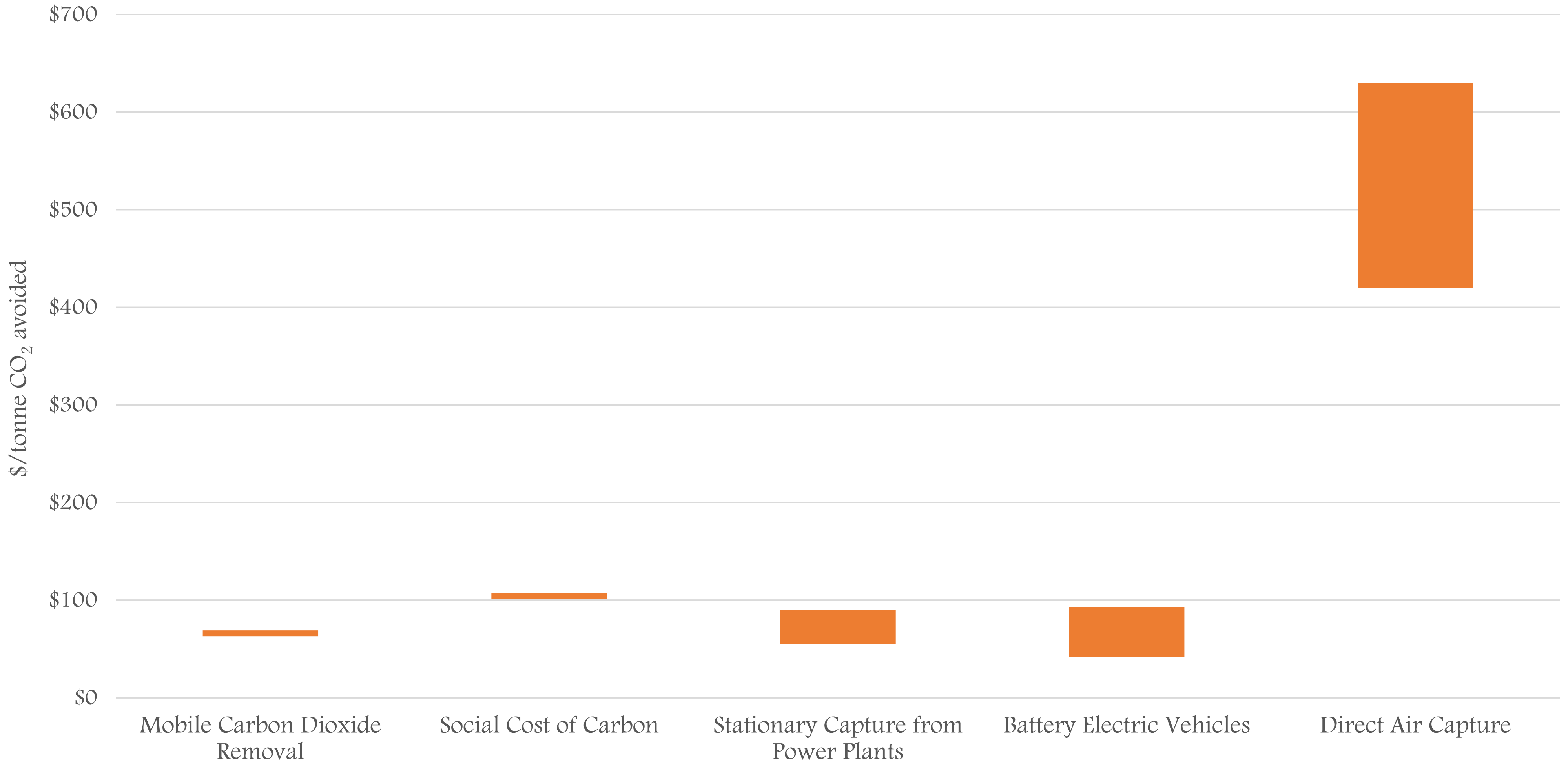
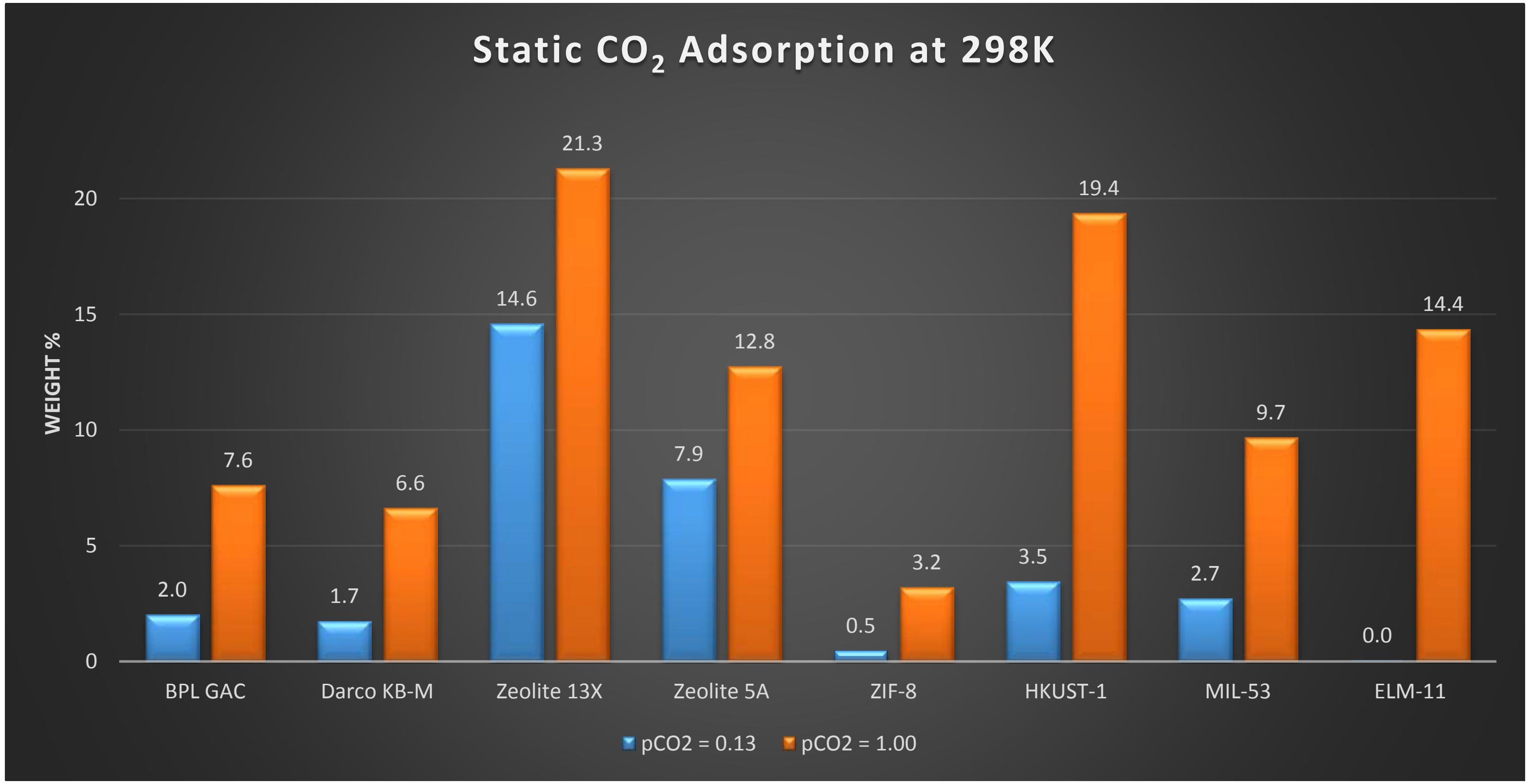
New annual shipping premium:	**$12.60**

MCDR costs are on par with other carbon capture methods and significantly less than DAC



Values from McKinsey, Supekar, Ranjan, Lutsey, & EPA

Testing protocol permits comprehensive evaluation of material performance



Static (@ 298-343K) →

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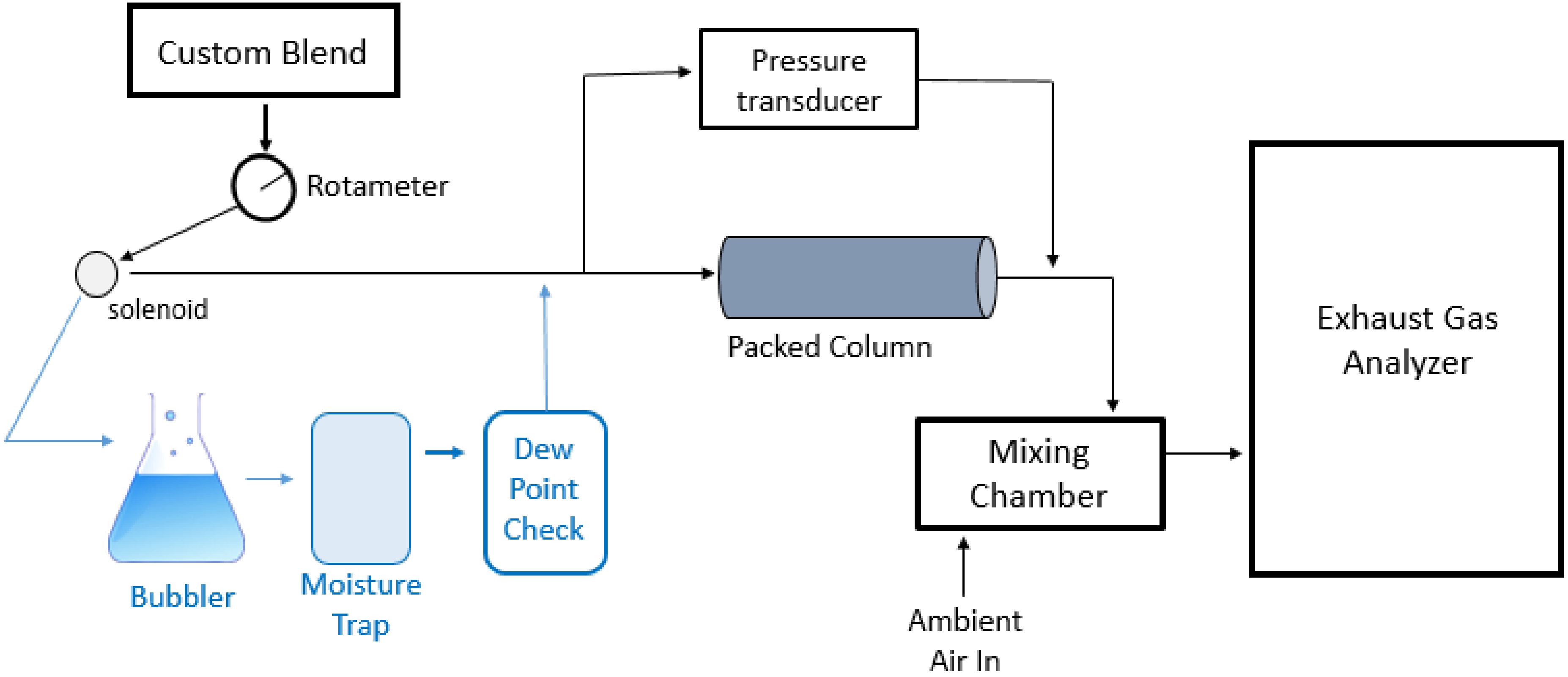

Static (@ 298-343K) → Dynamic, N_2-CO_2 blend → Dynamic, exhaust blend → Dynamic, wet exhaust blend —

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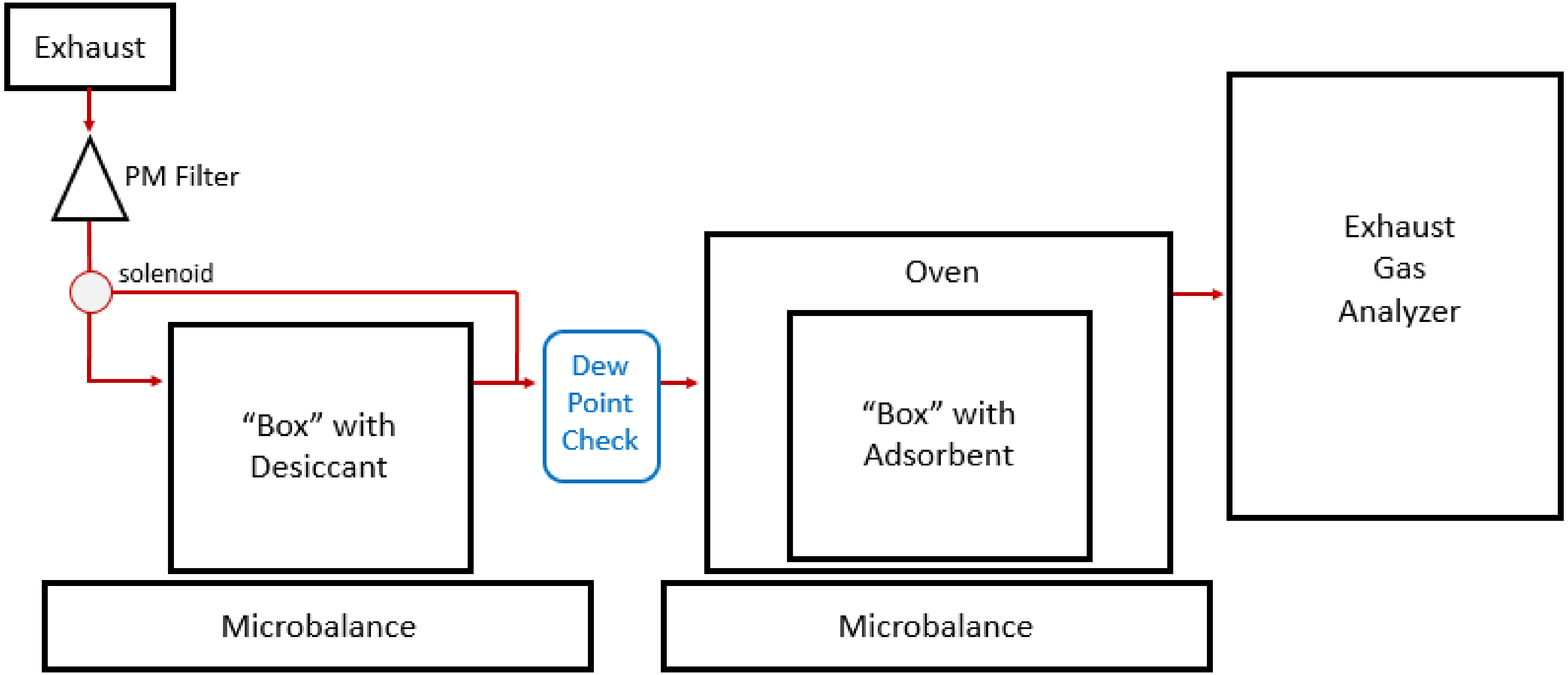

Static (@ 298-343K) → Dynamic, N_2-CO_2 blend → Dynamic, exhaust blend → Dynamic, wet exhaust blend → Proof-of-concept (1:4 scale) using actual exhaust

Conclusions and next steps

- Mobile carbon dioxide removal is theoretically feasible and economical
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