



Electric Vehicle Power Beaming

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01

Gas vs Electricity

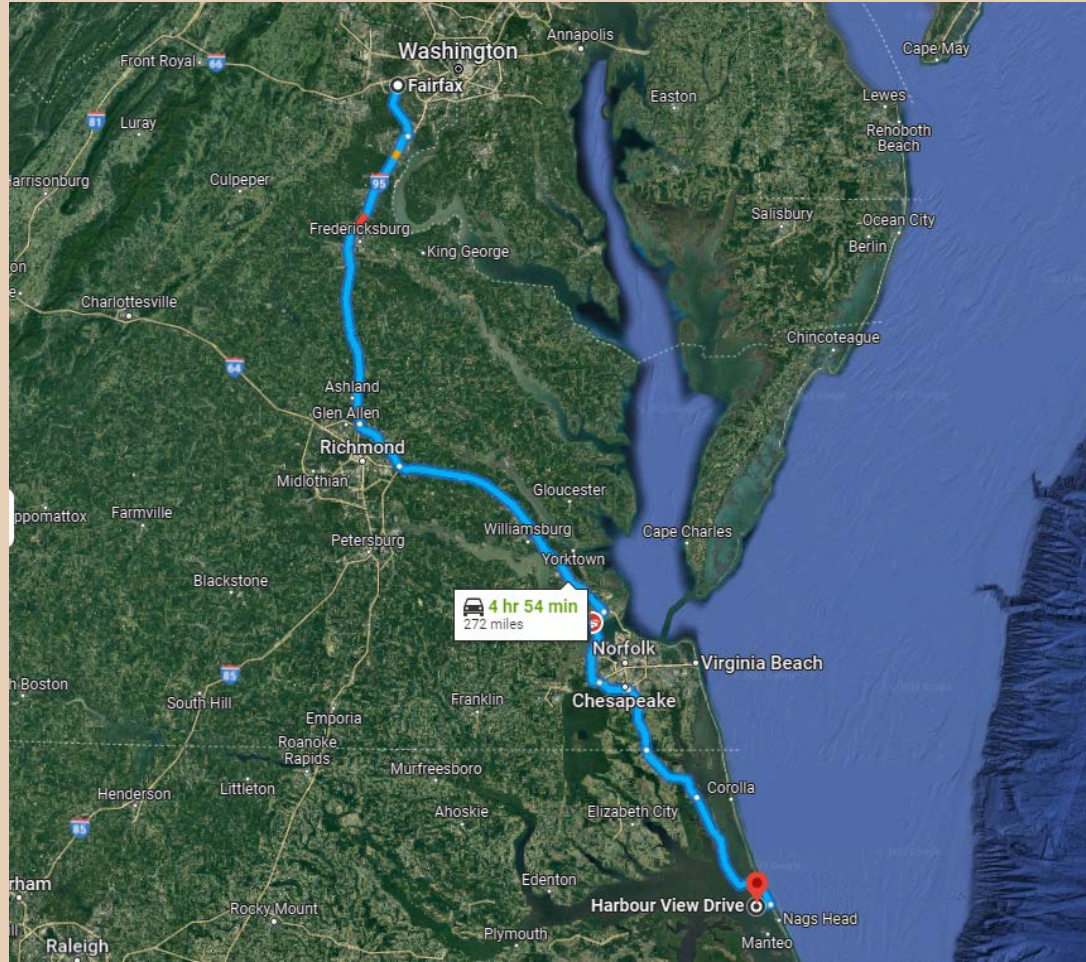




Beach Week - Outer Banks



Fairfax, VA to OBX House



272 Miles

Trip Distance

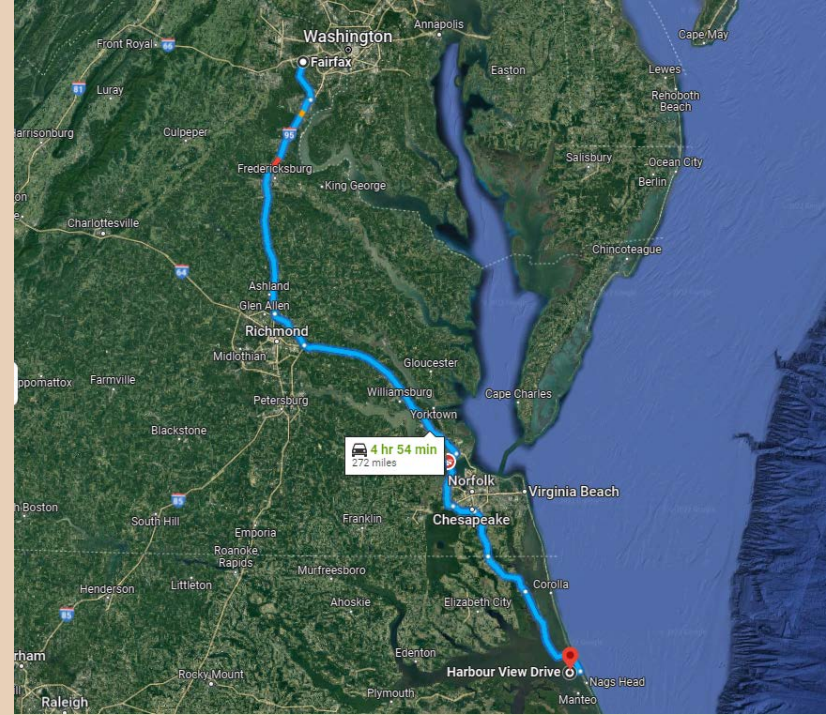
2007 Hyundai Sonata

Avg. 23 MPG

\$52.39

@ \$4.43 / gallon

4h 54m



272 Miles

Trip Distance

2020 Tesla Model X Long Range

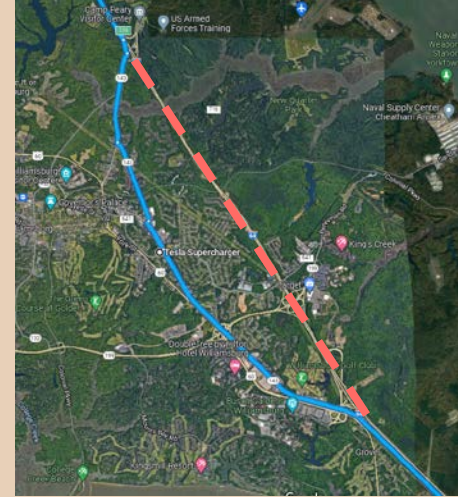
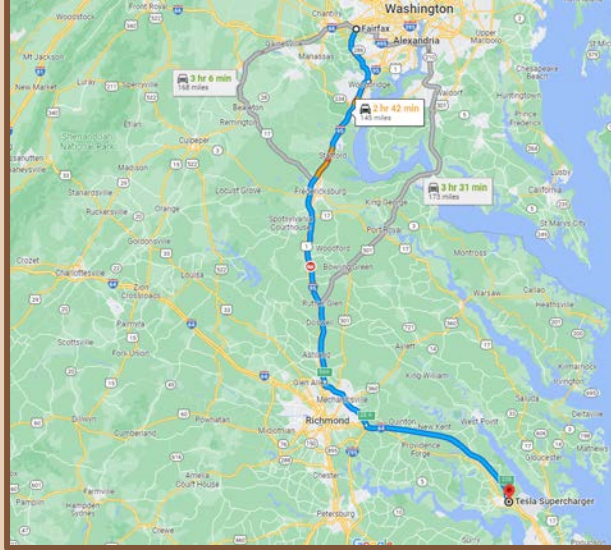
108 city / 101 highway MPGe

25 Minutes Charging

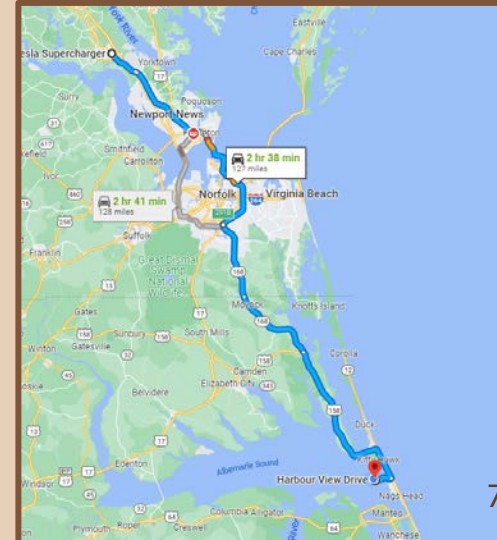
\$22.41

@ \$25 / kWh

5h 19m



Diversion to Supercharge





Trip Comparison



2007 Hyundai Sonata

Fuel Cost: \$52.39

Time: 4h 54m

2020 Tesla Model X Long Range

Fuel Cost: \$22.41

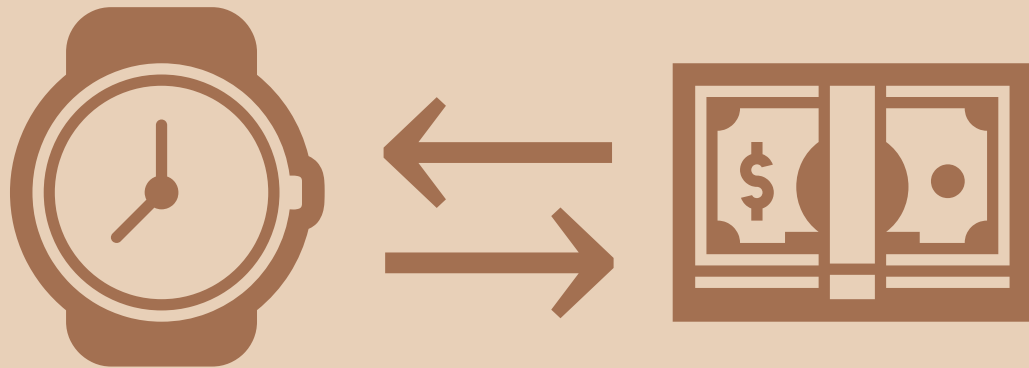
Time: 5h 19m

Time Fueling: \$27.08

Total: \$49.49

Time Difference Billed at \$65/hour: 25m * \$65/hr = \$27.08

\$65/hour is average hourly salary of EV owners





02

Problem Statement





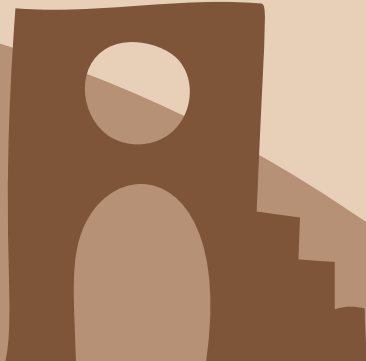
EVs - Two Problems

Range

At all price levels, finding an EV that can rival gas range is difficult.

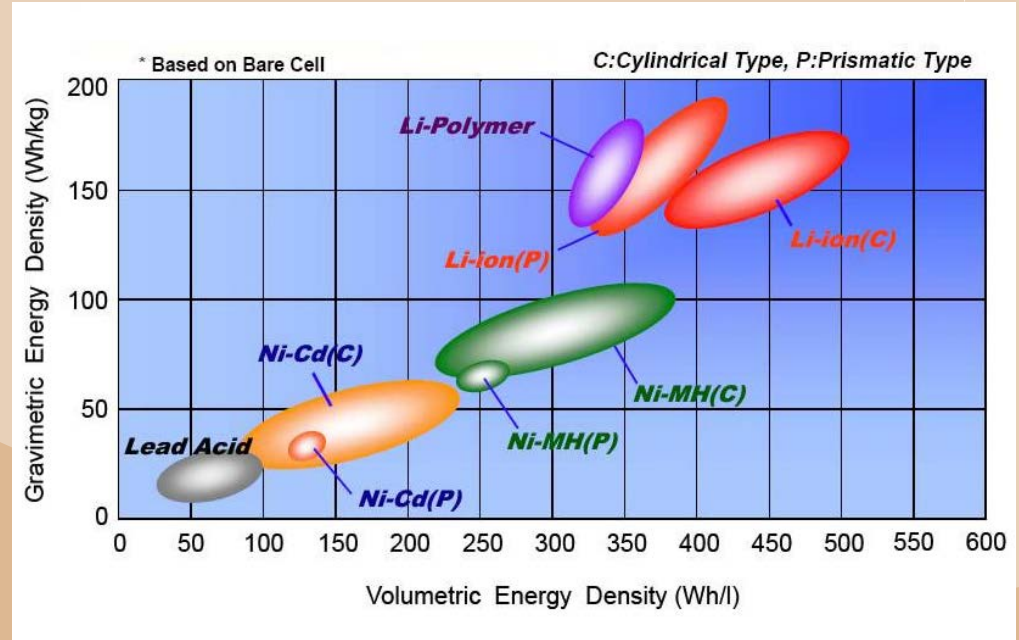
Charge Speed

Liquid gasoline transfers energy much more quickly than the fastest chargers.



Range Potential Solutions

- Bigger battery
 - Adds weight
 - High cost
- More energy dense battery
 - Battery technology requires lots of time, research, and money to improve



Gasoline Volumetric Energy Density: 9700 W h/l

Charge Speed Potential Solutions

- Charge faster
 - Degrades battery
 - Reduces lifetime of battery
- Battery swap
 - Battery does not live with original owner
 - A swap could result in receiving a “worse” battery
 - Multiple battery configurations





03

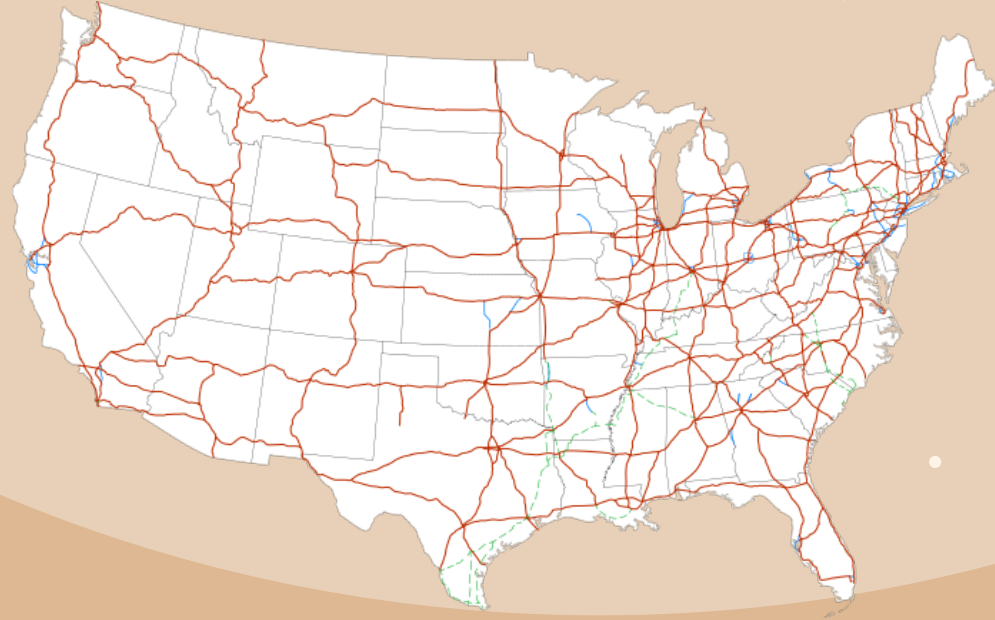
*Solution: Power
Beaming*





Target Market

- 4-wheel EVs
- Vacation or long trip
- Interstates only



46,876 miles of US interstate
highlighted in red



German Electric Trucking Cables

\$5 million per mile

Very high efficiency

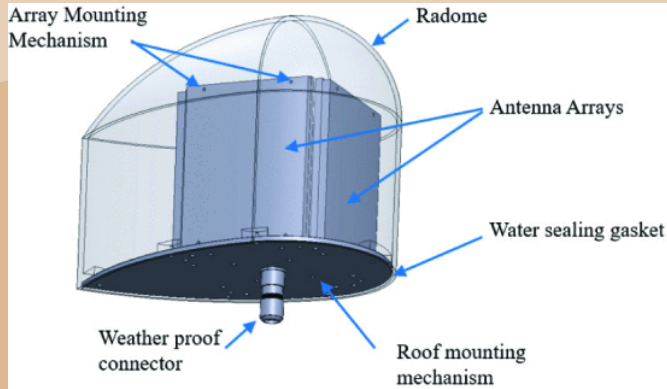
Single lane

Cannot be used by cars



Components

- Power beaming turrets
- Roof-mounted receivers



Car Mounted Radome Design

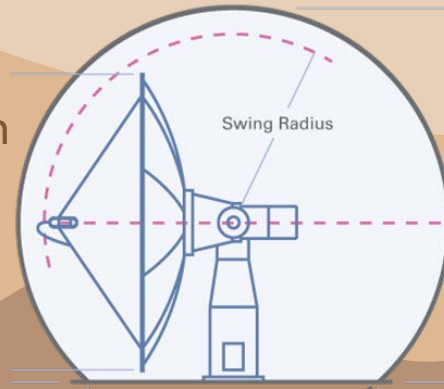


Power Beaming Turrets

- Frequency: 94 GHz, W band
- Target Power Level: 24 kW
 - Based off of 2022 Nissan Leaf at 70 mph
- Line-of-sight
- Pan-tilt tracking of vehicles
- Parabolic antenna
 - Minimal side lobe
 - 3m diameter
 - High gain
 - 0.07° Half-Power Beam Width
- Radome
 - Weather protection

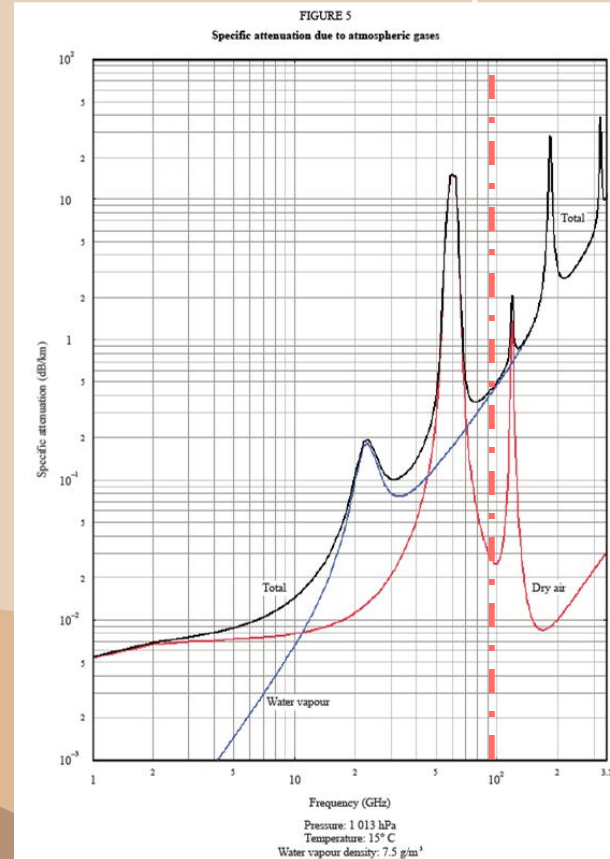


mWave HRP3-940,
0.9m diameter, W band



94 GHz Frequency Selection

- Acceptable atmospheric losses
- Tight beam
- Lots of human effects research from Active Denial System
 - Heats outer 1/64th of an inch of skin
 - No permanent damage



Active Denial System

- Frequency: 95 GHz
- 200 kW draw, 100 kW beamed
- Steerable
- 1.3 m² antenna
- VGB-8095 Gyrotron



Tracking + Safety

- Pan-tilt tracking unit
 - High resolution
- Local GPS and transponder based system
 - Precise position can be determined using the network of turrets
 - Transponder pings vehicle location
 - Signals want for beamed power
- Detects beam entry
 - Predicts bird path entry
 - Shuts off beam if power level changes unexpectedly
- Metal vehicle roof provides shielding



Moog APT-500

Roof-Mounted Receiver

Option 1 - Parabolic Antenna

- 1 m diameter
- Higher RF-to-DC efficiency

Option 2 - Phased Array

- Smooth with roof, aerodynamic
- Lower RF-to-DC efficiency
- Better manufacturer integration



Per-vehicle, options may differ in utility



Kitsap Composites- HAMMR 2 Radome



04

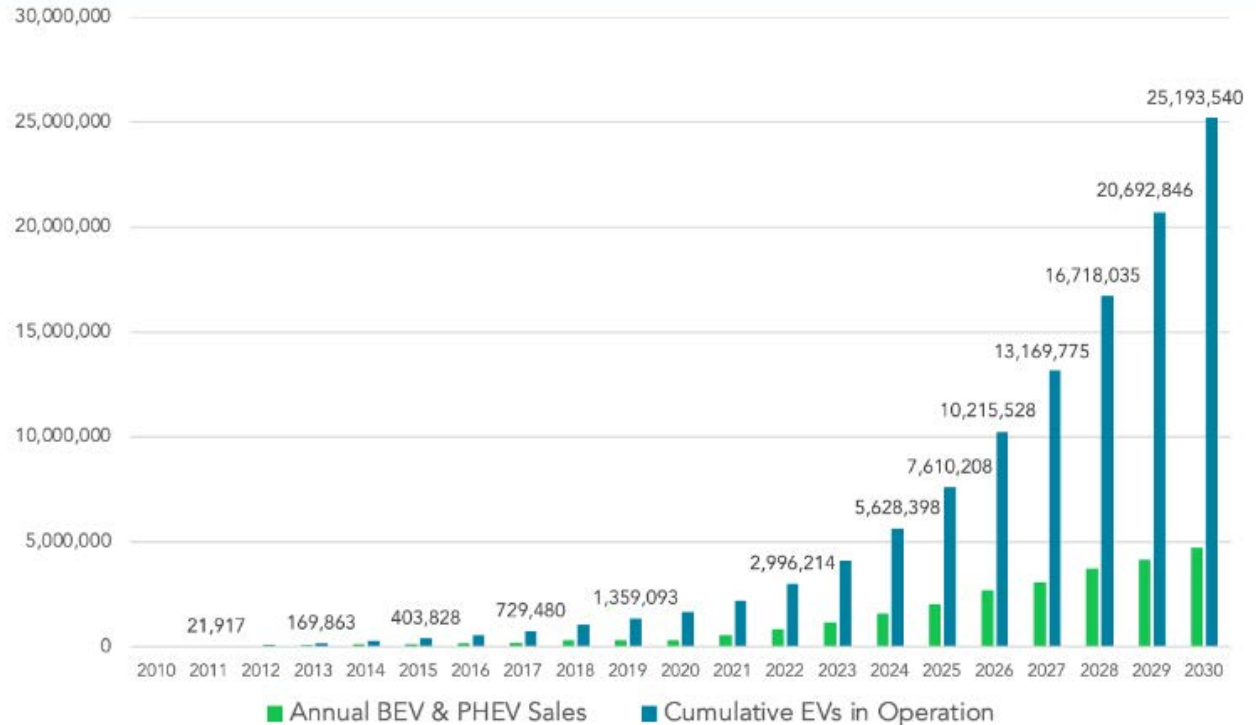
Financials



Market Size

For calculation:
20 million customers

Cumulative US Electric Vehicles In Operation: 2010-2030



Historical Data: GoodCarBadCar.net, InsideEVs, IHS Markit | Auto Manufacturers Alliance, Advanced Technology Sales Dashboard | Research, Forecast & Chart: Loren McDonald / EVAdoption

Cost Factors

Average Distance Traveled by American Driver (mi) Per Year	14263	Work Miles Proportion	0.9
Work Miles	12836.7	Work City Proportion	0.5
Work City Miles	6418.35	Work Highway Proportion	0.5
Work Highway Miles	6418.35	Travel Miles Proportion	0.1
Travel Miles	1426.3	Travel City Proportion	0.15
Travel City Miles	213.945	Travel Highway Proportion	0.85
Travel Highway Miles	1212.355	\$/kWh at home/grid/L2	\$0.11
		\$/kWh beamed	\$0.85
		Cost per kWh L3	\$0.43
		Waiting time value (L2/3) (\$/h)	\$65.00
		Level 3 Power level (kW)	150
		Level 2 Power level (kW)	12
		Cost per gallon	\$4.59
		DC-DC	26%

Gas vs Electric Cost

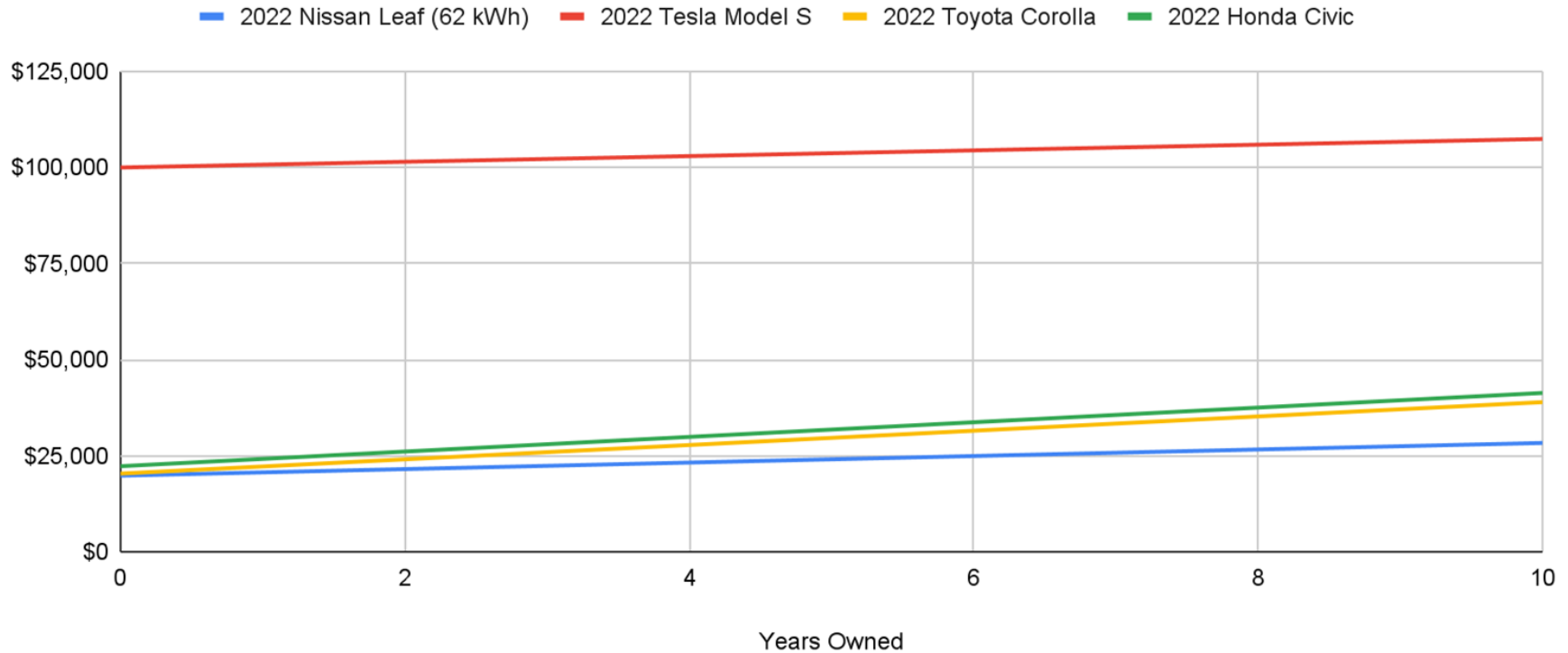
Car Model	Vehicle Type	MPG(e) City	MPG(e) Highway	Work Miles Cost	Travel Miles Cost	Annual Fuel Cost
2022 Nissan Leaf	EV	118	97	\$465.61	\$384.29	\$849.90
2022 Tesla Model S	EV	124	115	\$415.45	\$326.98	\$742.43
2022 Toyota Corolla	ICE	31	40	\$1,687.94	\$170.91	\$1,858.85
2022 Honda Civic	ICE	31	38	\$1,726.73	\$178.23	\$1,904.96

Average Distance Traveled by American Driver (mi) Per Year	14263
Work Miles	12836.7
Work City Miles	6418.35
Work Highway Miles	6418.35
Travel Miles	1426.3
Travel City Miles	213.945
Travel Highway Miles	1212.355

Electric: Low grid charging, high vacation cost, stable
Gas: High (as of 5/25/22), unstable, not eco-friendly

Gas vs Electric

Car Ownership Costs: MSRP plus Fuel Over Time



Per Turret

Component	Price
Pan Tilt Unit	\$32,200
Dish	\$20,000
Tower	\$175,000
Communications	\$10,000
Radome / Shroud	\$1,627
Total	\$238,827
Annual Land Rights Per Tower	\$5,000

Overall Cost

Cost Per Turret	\$238,827
Turret Radius (km)	0.30
Miles of Interstate	46,876
Min Highway MPGe to Maintain Charge	97
Top Speed (mph)	70
Coverage Overlap	1.00
Avg. Turret Target Power to Car (kW)	24.32
Turrets Needed	125,732.72
Total Cost	\$30,028,368,591
Alternatives	
German Overhead Trucking Cables	\$234,380,000,000
Electreon Induction Charging	\$89,064,400,000
New Construction Cost, 1 Addl. Lane, Rural Interstate, FL	\$31,291,237,532

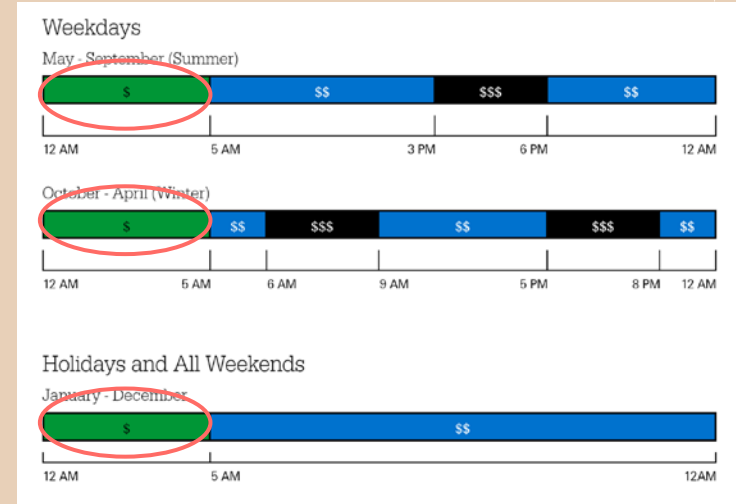


ROI Potential

Initial Installation Cost	\$30,028,368,591
Avg. Annual Profit per Customer	\$162.03
Annual Lease Cost	\$628,663,606
Customer Base	20,000,000
Annual Customer Miles Supplied	24,247,100,000
Annual Profit	\$2,611,952,721
Years to Break Even	11.50

Unlocks New Driving Style

- Enable self-driving at night and sleep on the way to your destination for off-peak rates
- Much better if the kWh price drops from ¢11 / kWh to ¢3 / kWh



Dominion Energy Smart Meter pricing

Summer Pricing for Weekdays, Weekends & Holidays

Review the pricing for the different tiers for the summer months (May - Sept)

Weekday Pricing	Price per kWh	Weekend & Holiday Pricing	Price per kWh
On Peak (\$\$\$)	\$0.214779	Off Peak (\$\$)	\$0.095533
Off Peak (\$\$)	\$0.095533	Super Off Peak (\$) (highlighted)	\$0.079082
Super Off Peak (\$) (highlighted)	\$0.079082		

Eligible holidays: New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving, and Christmas.

Multi-Use Turrets

- Power Beaming
- Cell Tower
- Self-driving “eyes in the sky”





Conclusion

- 94 GHz Power Beaming Turrets
 - Target: 4-wheelers
 - Freedom of movement, self-driving future
 - No stopping for fuel, battery as buffer
- Overhead Electric Cables
 - Target: Trucks and buses



Thanks!

Does anyone have any questions?

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