# DRIVING TO A SUSTAINABLE FUTURE:


# A NEW DNA FOR THE AUTOMOBILE

**LARRY BURNS**

Vice President, R&D and
Strategic Planning,
General Motors Company

GM

# TRANSFORMATIONAL CHANGE

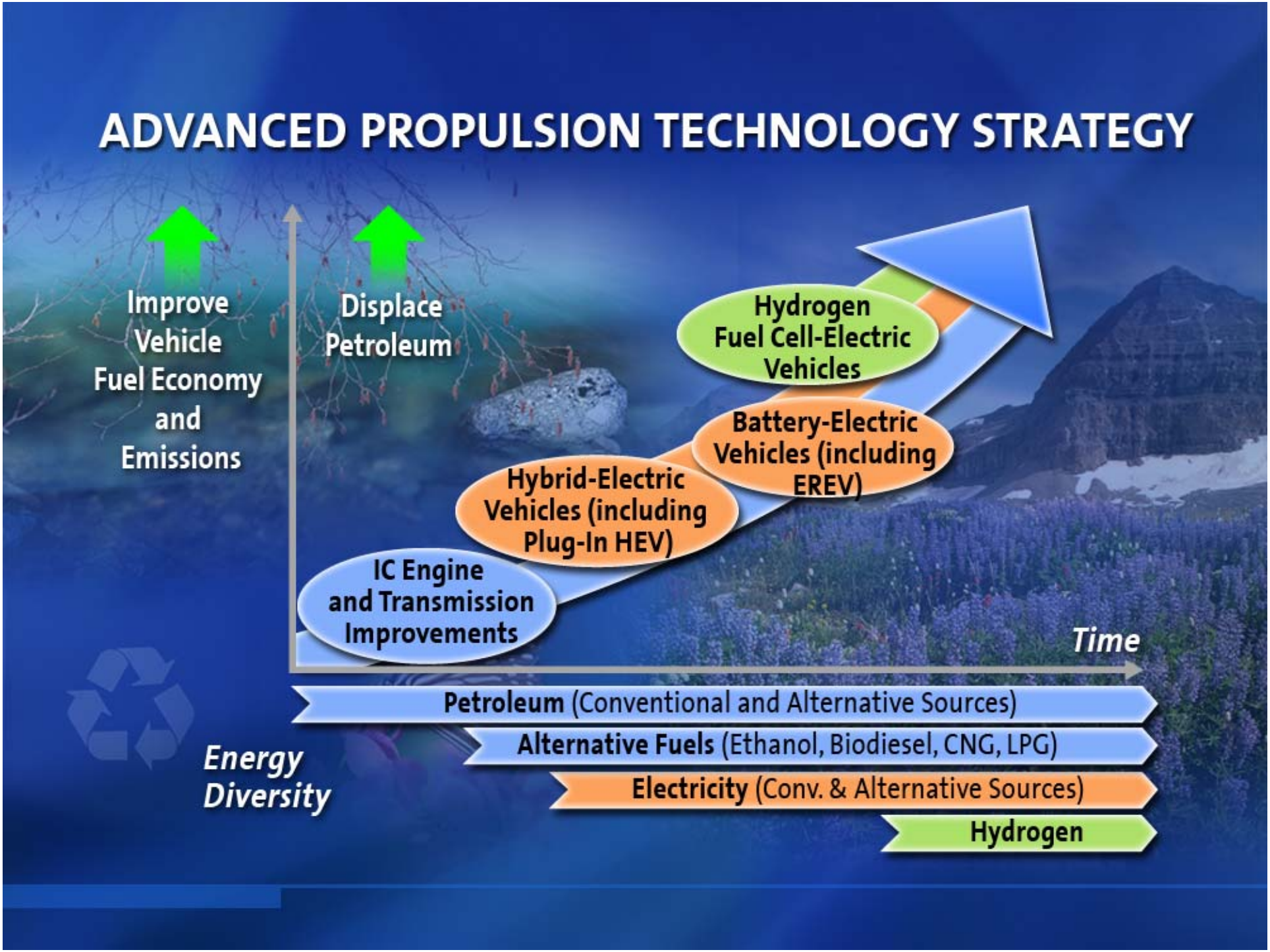
## CURRENT DNA

- Mechanically driven
- Energized by petroleum
- Powered by internal combustion
- Controlled mechanically
- Stand-alone

## NEW DNA

- Electrically driven
- Energized by electricity and hydrogen
- Powered by electric motors
- Controlled electronically
- “Connected”

# FREEDOM AND SUSTAINABIITY


ADVANCED PROPULSION TECHNOLOGY STRATEGY
Improve Vehicle Fuel Economy and Emissions
Displace Petroleum
Hydrogen Fuel Cell-Electric Vehicles
Battery-Electric Vehicles (including EREV)
Hybrid-Electric Vehicles (including Plug-In HEV)
IC Engine and Transmission Improvements
Time
Petroleum (Conventional and Alternative Sources)
Alternative Fuels (Ethanol, Biodiesel, CNG, LPG)
Electricity (Conv. & Alternative Sources)
Hydrogen
Energy Diversity

# "AND" NOT "OR"

- Scale of the challenge
- Diverse consumers
- Portfolio of promising solutions
- Synergy in total system

# FULL PORTFOLIO OF SOLUTIONS

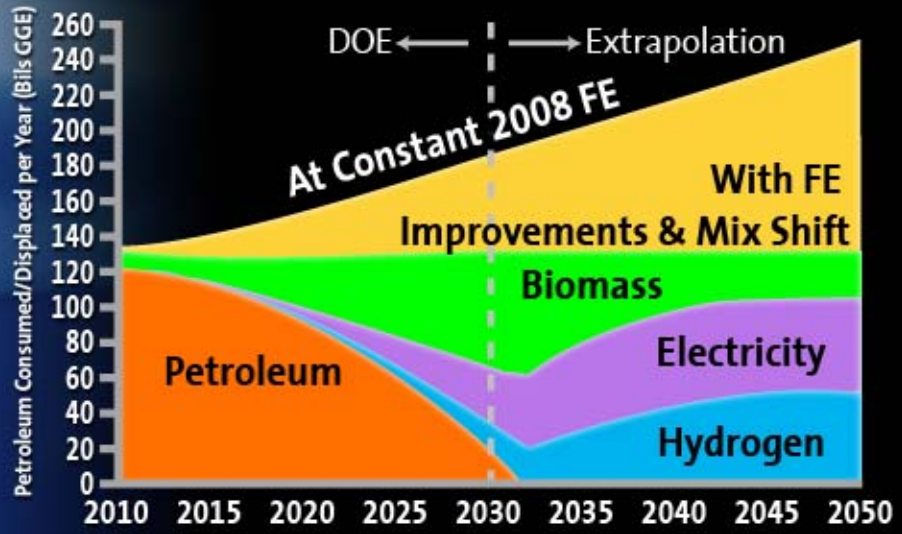
| Gasoline/ Diesel | Corn Ethanol | Current Electric Grid | Compressed Natural Gas | Cleaner Electric Grid | Natural Gas to Hydrogen | Cellulosic Biomass | Nuclear Electricity | Renewable Electricity |
|---|---|---|---|---|---|---|---|---|

FOR VEHICLE CHARGING/HYDROGEN

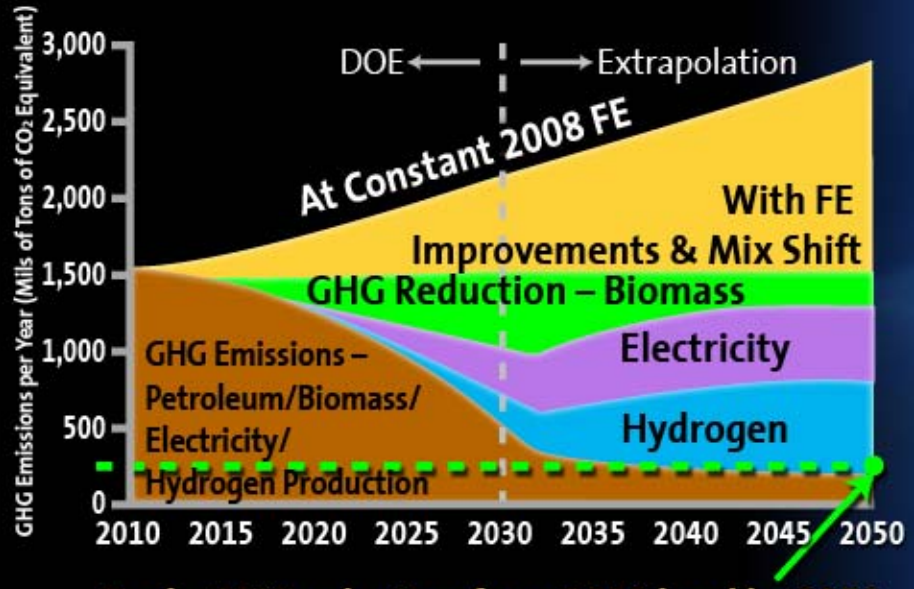
CLEANER

# THE POWER OF "AND" – SCALE

## Petroleum Consumption




## GHG Emissions




**START SOON WITH EARLY OPTIONS**

**FINISH JOB WITH STRONGEST LONG-TERM PORTFOLIO**

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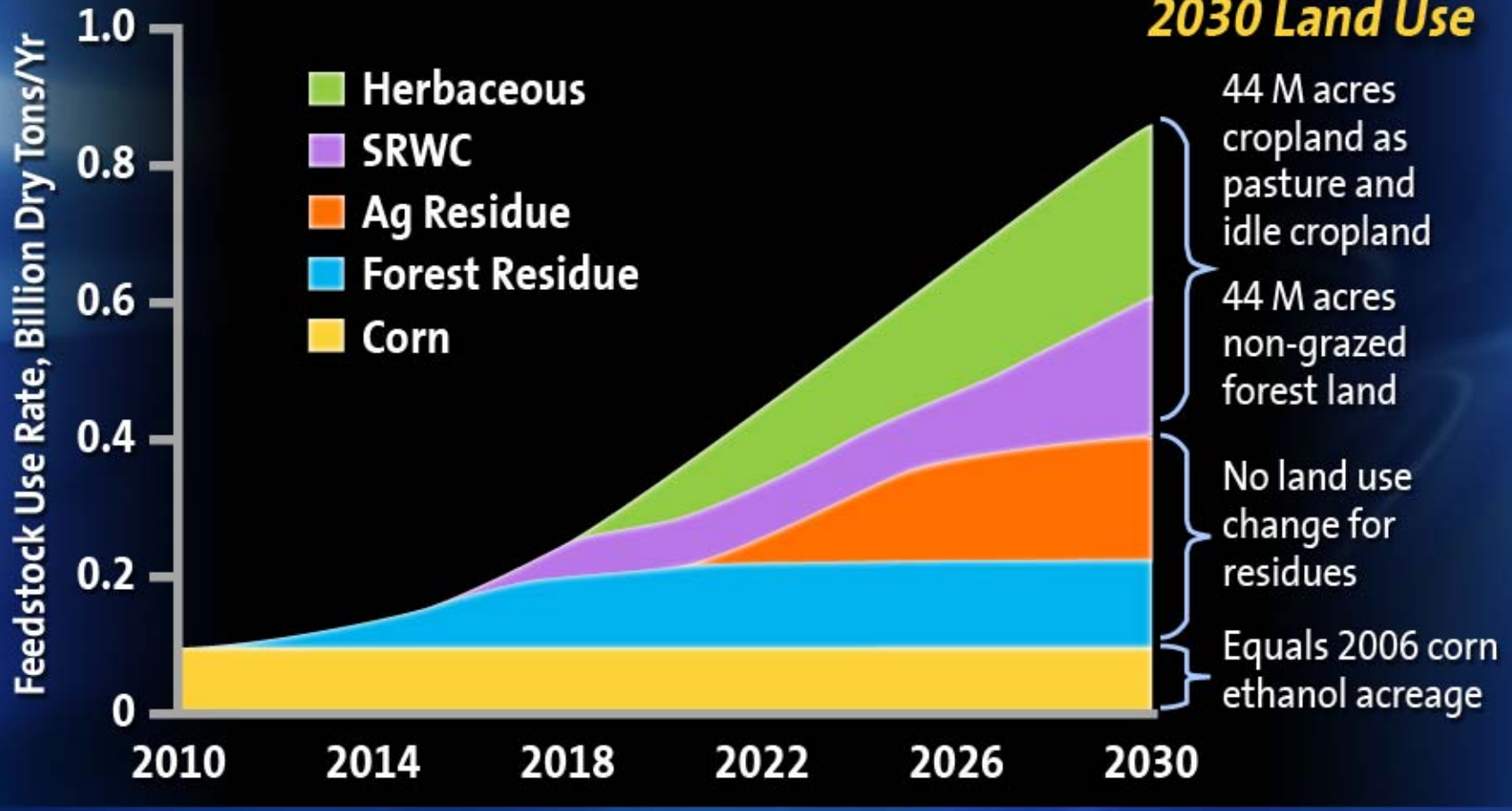
# GM SANDIA STUDY:
# BIOMASS FOR 90B GALLONS OF ETHANOL



# GM ETHANOL VEHICLES


## OVER 5M VEHICLES WORLDWIDE AND 20 MODELS IN NORTH AMERICA

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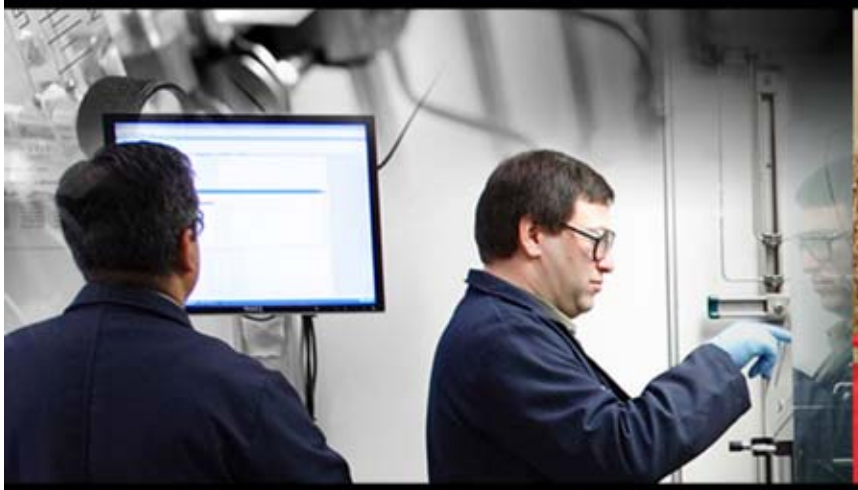

coskata

MASCOMA

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# GM'S PATH TO ELECTRIFICATION


Internal Combustion Engine

Hybrid

2-Mode Hybrid

2-Mode Plug-in Hybrid

Extended-Range Electric Vehicle

Battery-Electric & Fuel Cell Vehicles

**INCREASING LEVEL OF EFFICIENCY & REDUCED EMISSIONS**

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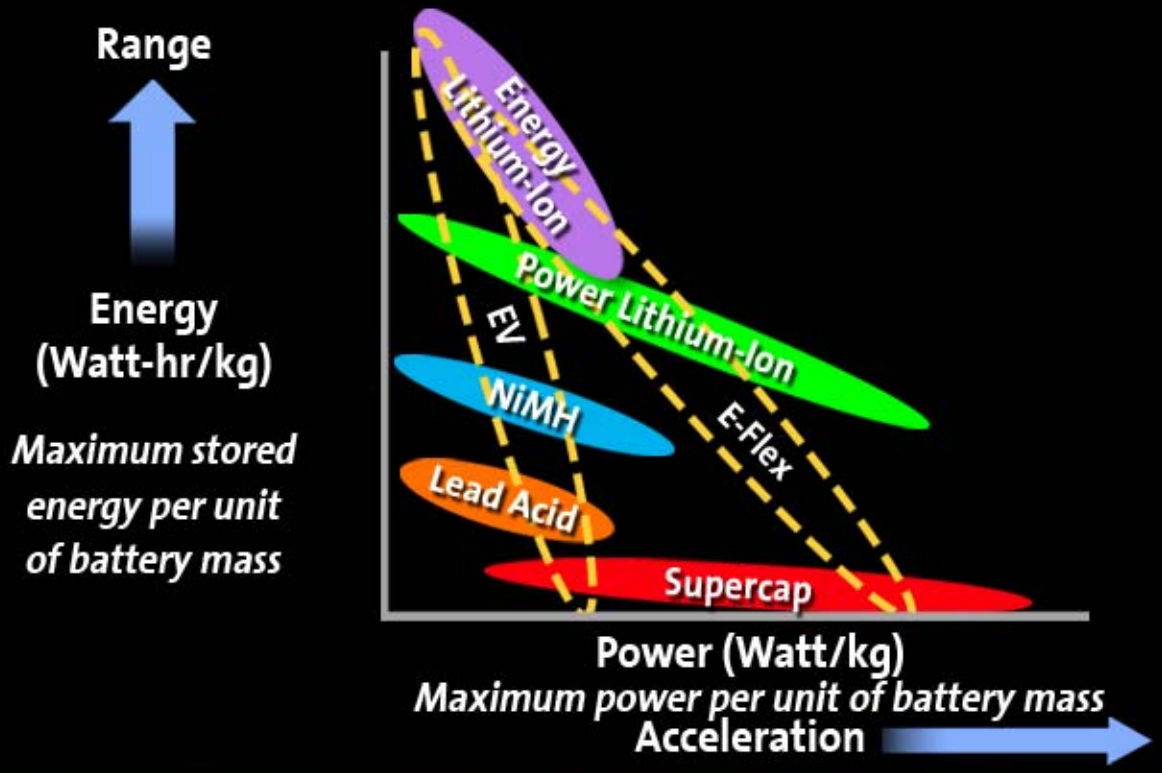
# CADILLAC ESCALADE 2-MODE HYBRID

- 40-50% city fuel economy improvement
- City fuel economy equal to 4-cylinder Camry
- Tow up to 6,200 pounds
- Most sophisticated hybrid system today

# BATTERY TECHNOLOGY IMPROVEMENTS




NEW LITHIUM-ION CELLS ARE MORE STABLE, WITH HIGHER ENERGY (RANGE) AND POWER DENSITY (ACCELERATION)

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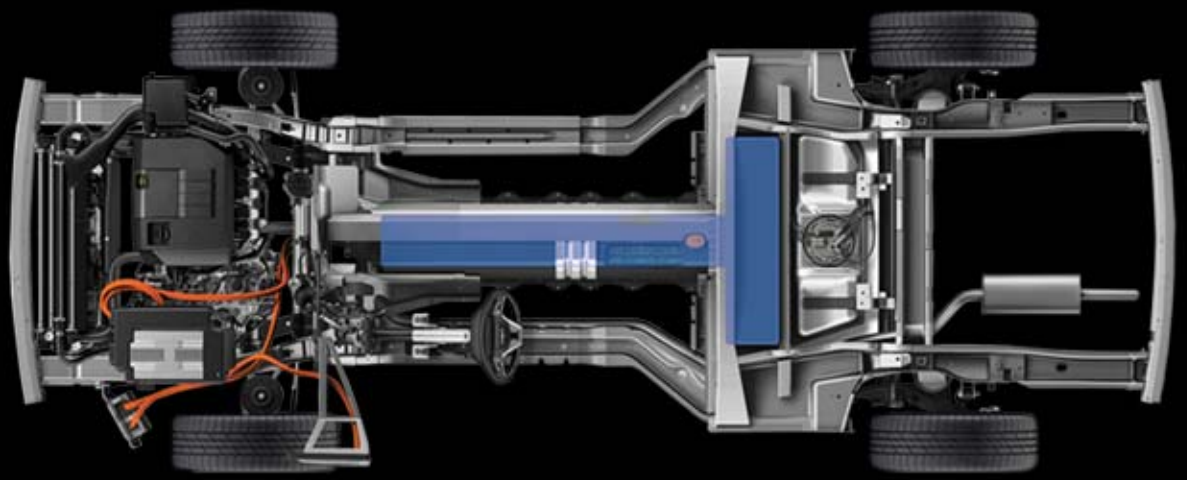
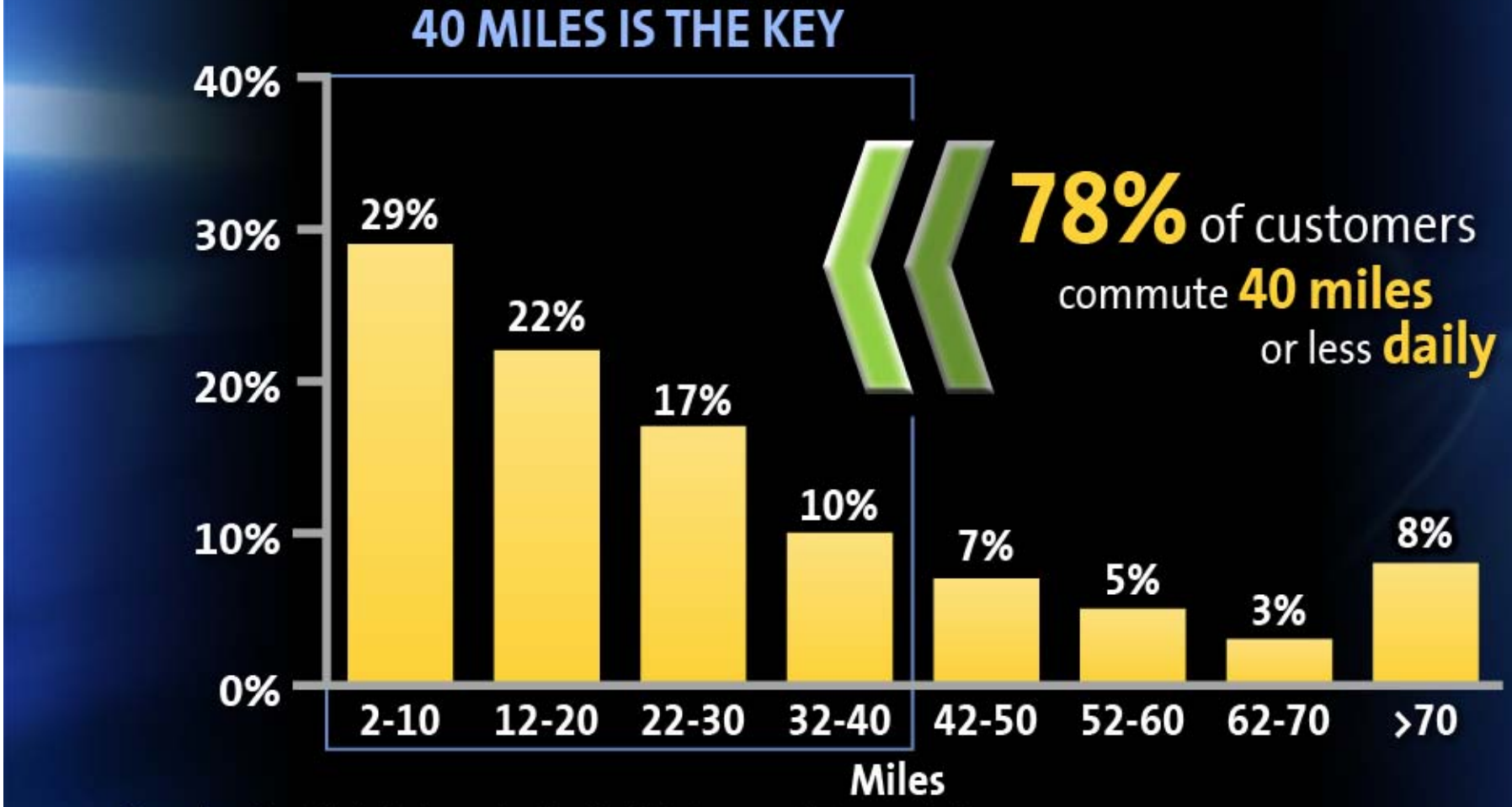
Engine / Battery Charge
40
MILES
GAS-FREE
VOLT


CHEVROLET VOLT

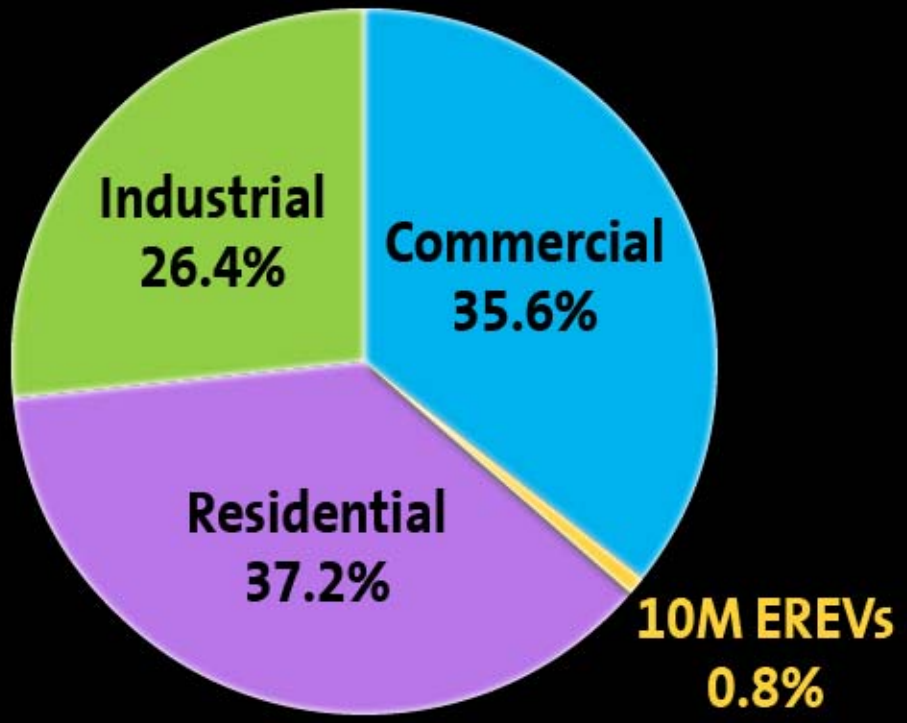
# TYPICAL DAILY COMMUTE – U.S.




Based on OmniStats Data posted by the U.S. Bureau of Transportation


KILOWATTHOURS
<3¢
PER MILE
VOLT

# IMPACT ON THE GRID




Electricity: An important energy source with significant capacity to support transportation

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10 million EREVs in 2010 would add a load that is less than 1% of the total grid load

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# GLOBAL BATTERY SYSTEMS LAB

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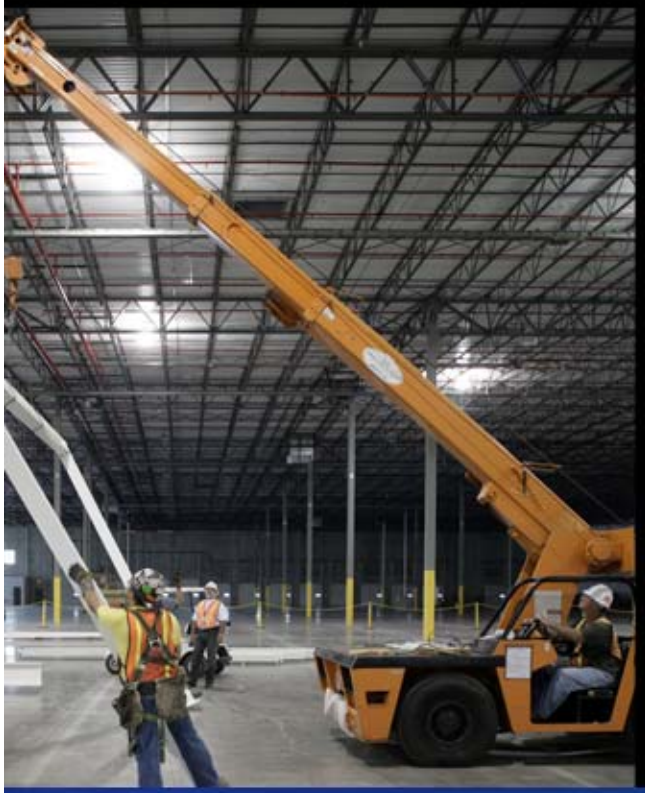
# BATTERY MANUFACTURING PLANT





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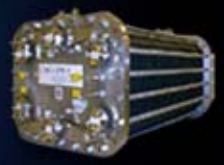
**3,000**
**ORDINARY DRIVERS**

**~1,000,000**
**MILES LOGGED**

# PROJECT DRIVEWAY

# GM FUEL CELL STACK PROGRESS


| ST3 1997 | ST4 1998 | Stack 2000 2000 | S2.1 2003 | S4 2004 | S5 2008 |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
| 37-41 kW | 40 kW | 80-120 kW | 85 kW | 130 kW | 80 kW |
| 0.26 kW/l | 0.77 kW/l | 1.30 kW/l | 1.31 kW/l | 1.64 kW/l | 3.0 kW/l |
| 0.16 kW/kg | 0.31 kW/kg | 0.76 kW/kg | 0.80 kW/kg | 1.00 kW/kg | 2.0 kW/kg |
| 80-195 cells | 106 cells | 200 cells | 200 cells | ~400 cells | |
| 500 $cm^2$ | 500 $cm^2$ | 800 $cm^2$ | 760 $cm^2$ | 360 $cm^2$ | |
| 2.7 bar | 2.7 bar | 1.5-2.7 bar | 1.2-2.5 bar | 1.5-2.0 bar | |

# GM FUEL CELLS:
# FUEL CELL PROPULSION SYSTEM OFFERS...

- Zero emissions/zero petroleum
- Compared to internal combustion engine:
  - More than twice as efficient
  - Promises comparable precious metal content
  - Promises equivalent durability, range (300 miles), and performance
  - 60% fewer part numbers
  - 90% fewer moving parts
  - Similar refueling time (~3 minutes)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# ENERGY CARRIER PROPERTIES: ONBOARD STORAGE

## WEIGHT AND VOLUME OF ENERGY STORAGE SYSTEM FOR 500 KM RANGE

### Diesel

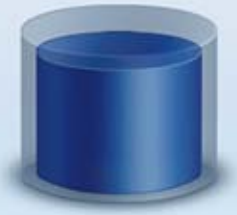
System 43 kg
Fuel 33 kg

46 L
37 L

### Compressed Hydrogen 700 Bar

6 kg $H_2$ = 200 kWh Chemical Energy

System 125 kg
Fuel 6 kg

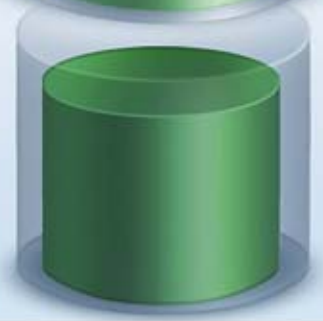


260 L
170 L

### Lithium-Ion Battery

100 kWh Electrical Energy

System 830 kg
Cell 540 kg

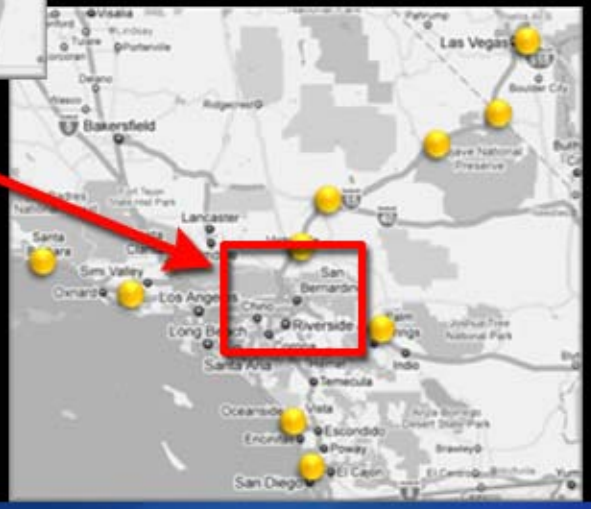


670 L
360 L

# HYDROGEN INFRASTRUCTURE ACHIEVABLE IN U.S.

## $100-200M INVESTMENT OPENS 15M-CUSTOMER REGIONAL MARKET

- 30 – 40 stations
  ~3.6 miles apart
  - Los Angeles Metro Area




- 10 stations ~25 miles apart on destination corridors
  - San Diego
  - Palm Springs
  - Las Vegas
  - Santa Barbara

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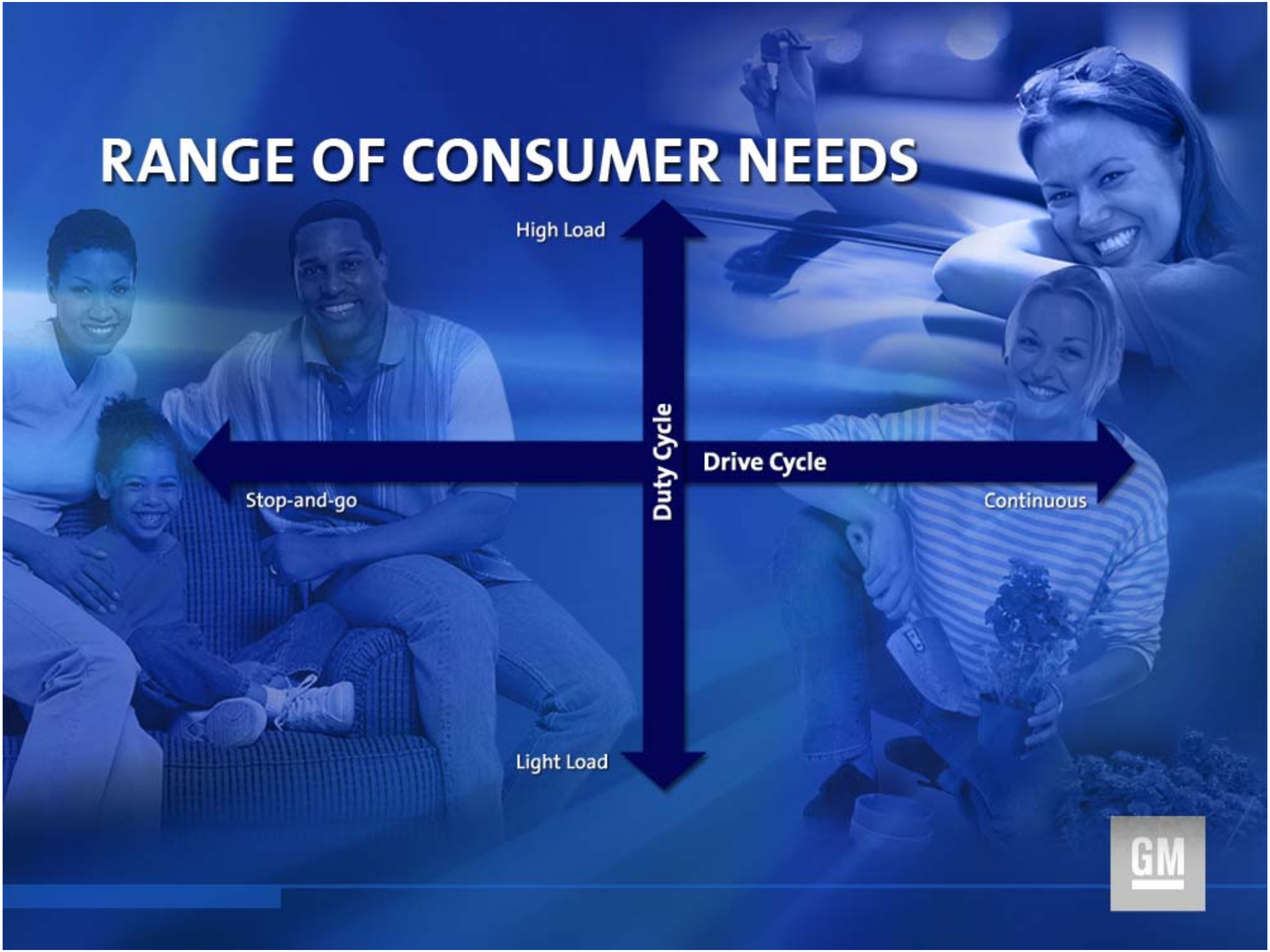
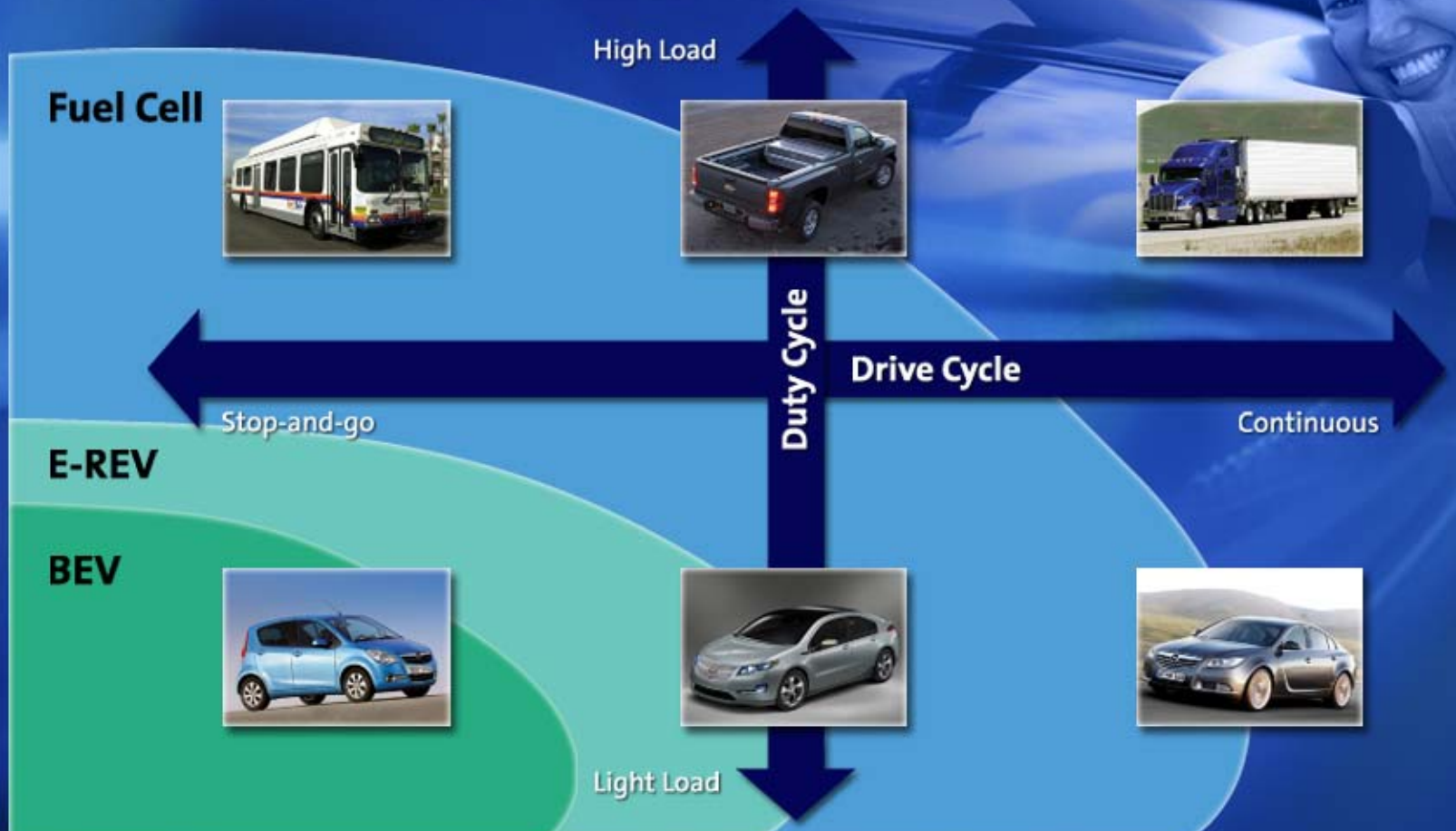
# RANGE OF CONSUMER NEEDS



# THE POWER OF "AND" – CUSTOMER SATISFACTION



# ELECTRICALLY DRIVEN VEHICLES

| | *Battery-Electric Vehicle* | *Extended-Range Electric Vehicle* | *Fuel Cell-Electric Vehicle* |
|---|---|---|---|
| Vehicle Size | ≤ Small | ≤ Compact | ≤ Family |
| Refueling Time | Hours | Hours (battery charging) | Minutes |
| Range (Miles) | 100+ | 40 (battery)/ 300+ (overall) | 300-400 |
| Performance | Excellent | Excellent | Excellent |
| Vehicle Emissions | Zero | Zero for 40 miles daily | Zero |
| Energy Source | Diverse/ petroleum free | Diverse/petroleum only with range extender | Diverse/ petroleum free |
| Refueling Infrastructure | Already available at home | Already available at home and stations | Must be deployed |

# THE POWER OF "AND" – SYNERGY

- Hydrogen from electricity **and** electricity from hydrogen
- Biomass to make liquid fuels **and** electricity **and** hydrogen
- HEVs, plug-in EVs, **and** FCEVs benefit from motors and power electronics
- Lower-cost lithium-ion power batteries enhance HEVs **and** FCEVs
- Renewable electricity from wind and solar stored in batteries **and** as hydrogen
- Electricity stored and created on board vehicles for transportation **and** stationary applications

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# CARS THAT DON'T CRASH

# VEHICLES THAT DRIVE THEMSELVES

***Where am I –*** GPS + digital maps

***What's around me –*** 360° sensing (sensors + "V2V")

***Take me where I want to go –*** Software algorithms + electronic controls and actuators

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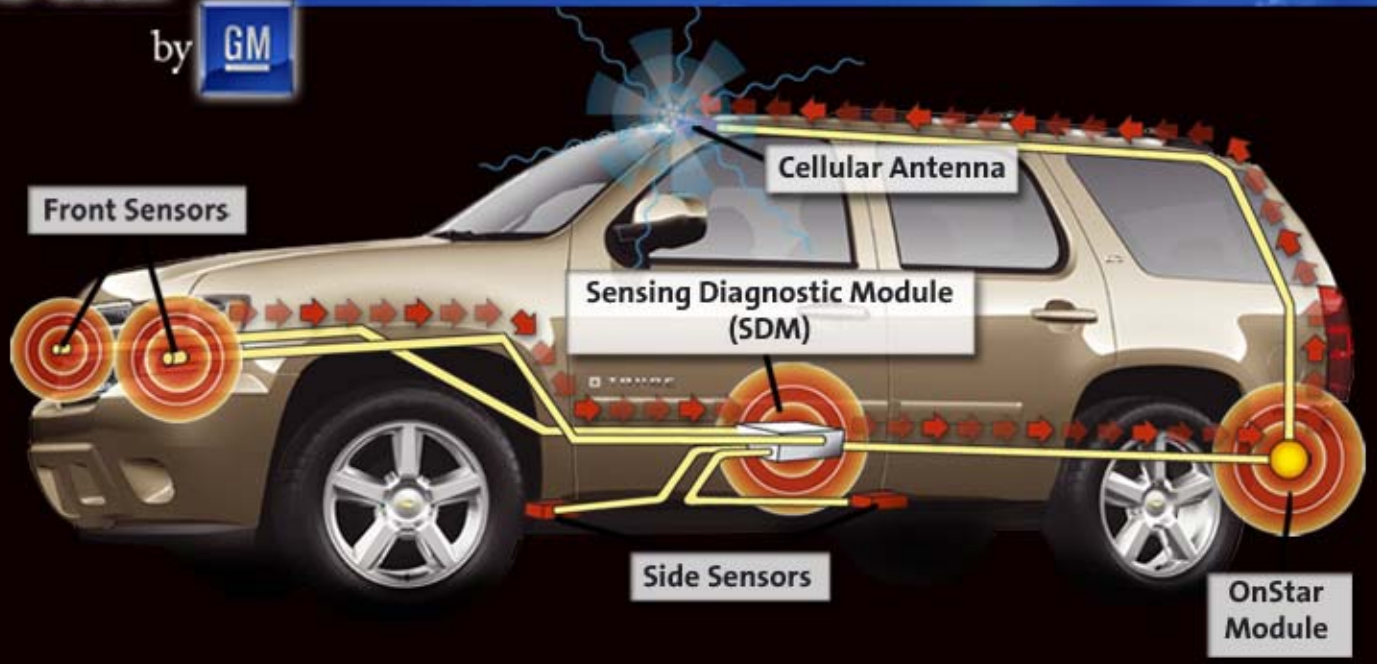
# "CONNECTED VEHICLES" SINCE 1996

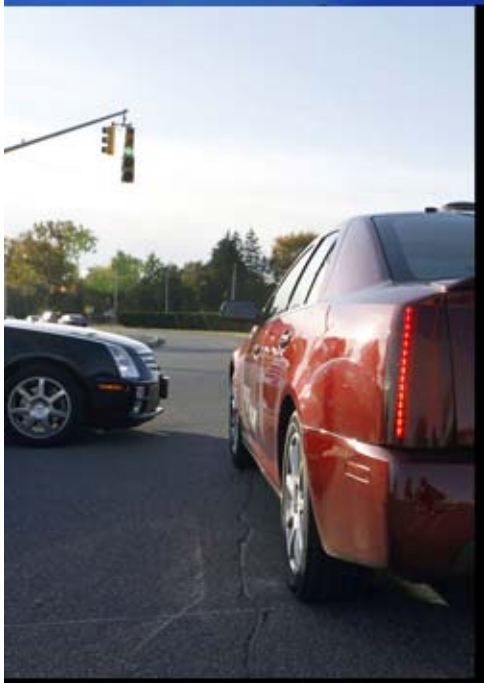
**6,000,000**
**SUBSCRIBERS**


OnStar by GM

## SAFETY AND SECURITY



# V2V/V2X COMMUNICATIONS



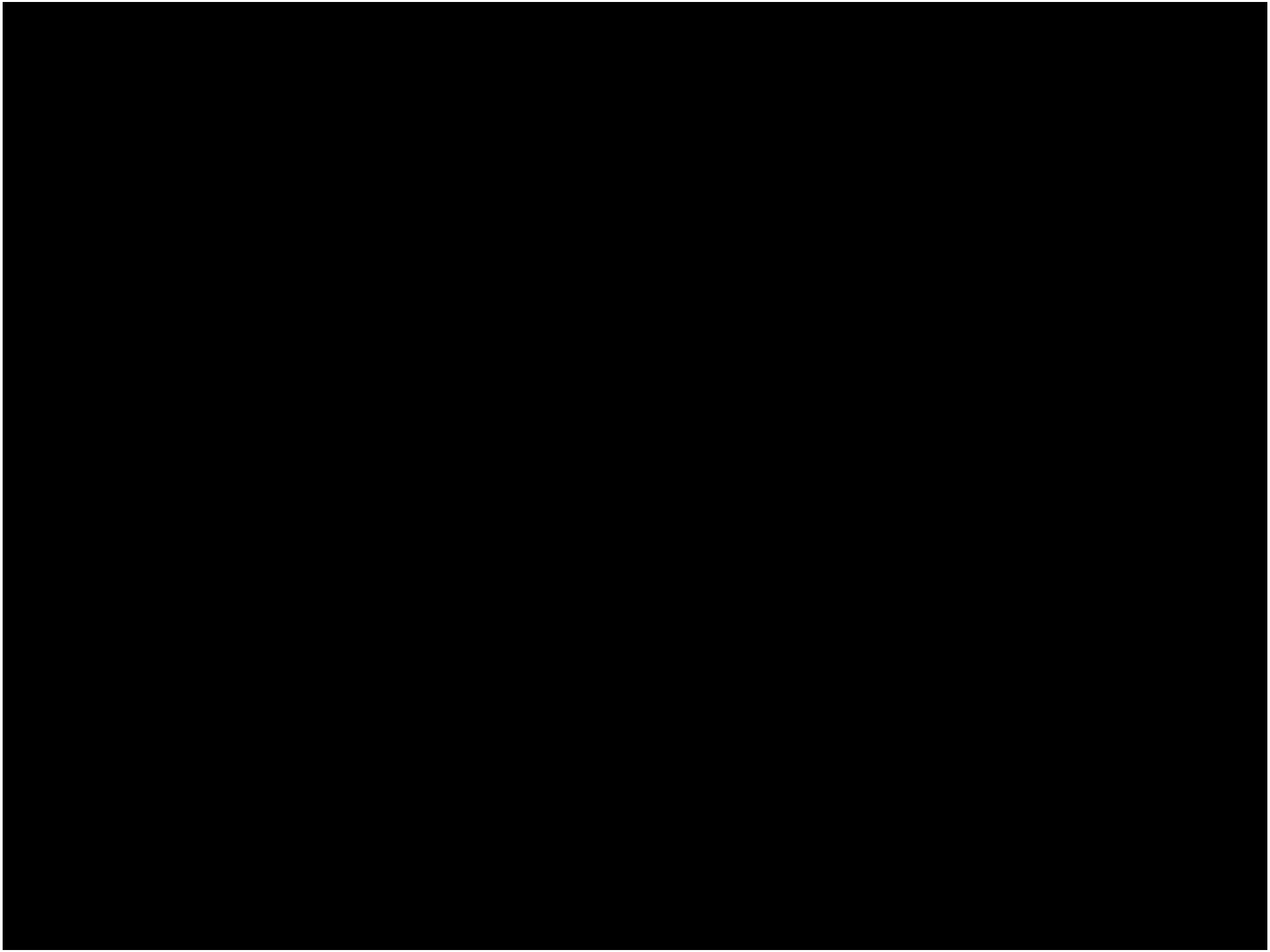
Embedded
V2V and V2I

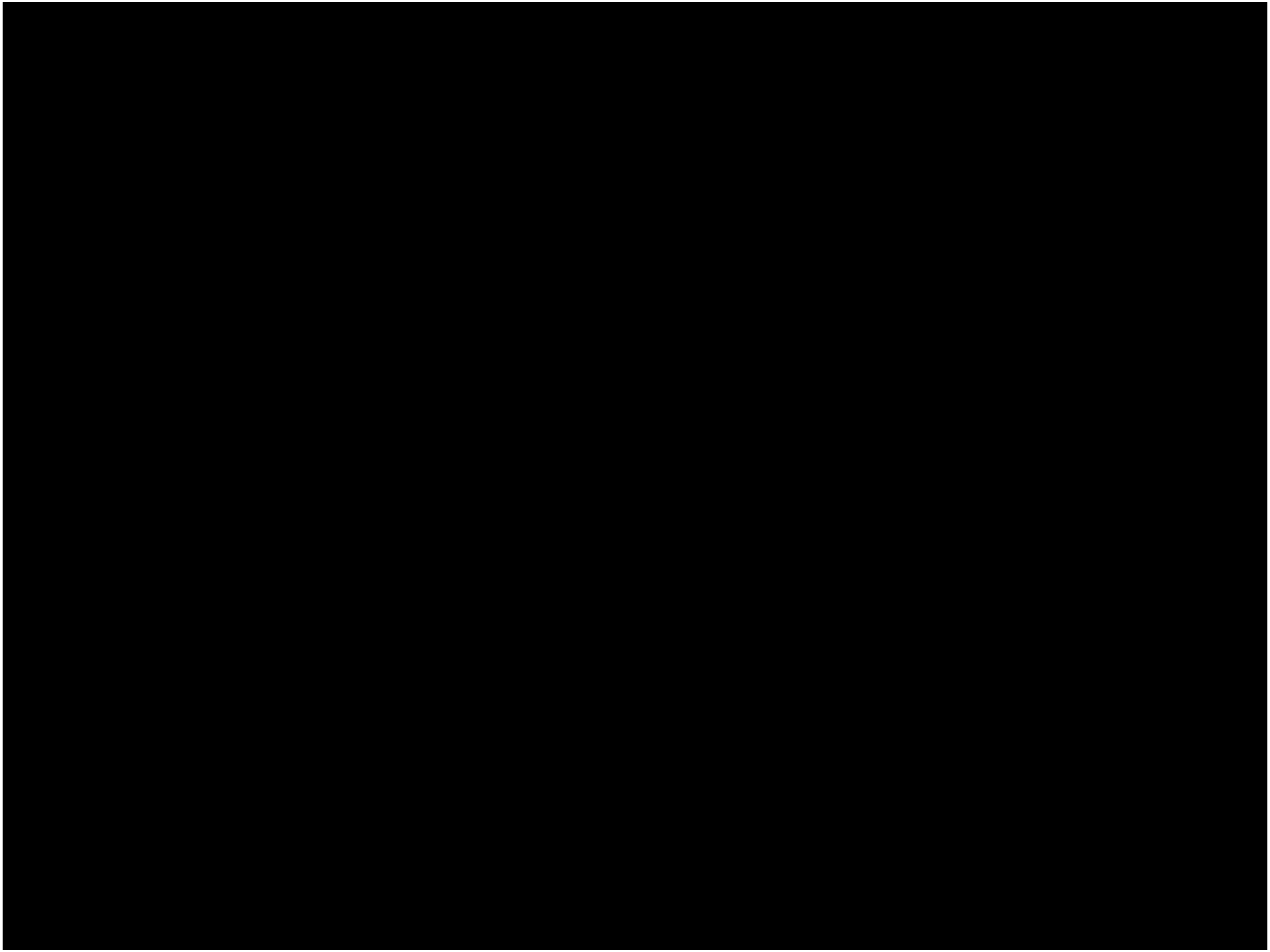

Standalone
V2X

Retrofit V2X


Transponder
(V2Pedestrian and V2Cyclist)

# “BOSS” WINS!





# P.U.M.A. EARLY DESIGN SKETCHES

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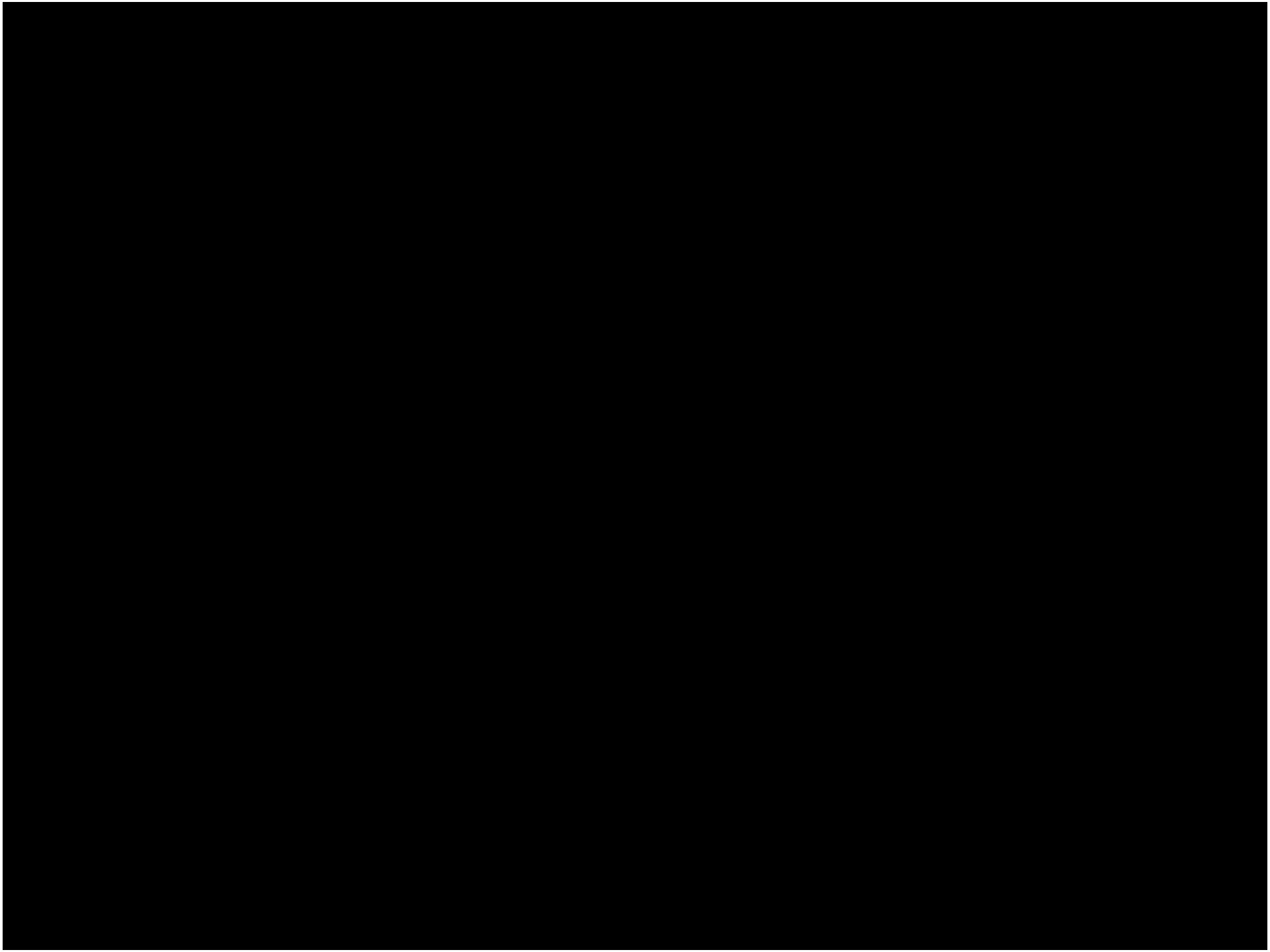

# "AND" NOT "OR"

THE WHOLE CAN BE GREATER THAN THE SUM OF THE PARTS




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# THE WHOLE IS MORE THAN THE SUM OF THE PARTS

***Converging Ideas***

Electrically Driven & Connected

+

Mobility Internet

+

Clean, Smart Energy

+

Pricing Markets

=

***Transformational Change in Personal Mobility***

- Zero Emissions
- Renewable Energy
- Crash Avoidance
- Safe Social Networking While Driving
- Fun Driving and Autonomous Driving (When Desired)
- Fashionable Designs
- Shorter, More Predictable Urban Travel Times
- Space- and Time-Efficient Parking
- Increased Roadway Throughput
- Quieter Cities
- Safer Pedestrians & Bicyclists
- More Equitable Access
- Lower Cost

=

Enhanced Freedom

+

Sustainable Mobility

+

Sustainable Economic Growth and Prosperity


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