SMART AND CONNECTED MOBILITY IN SMART CITIES: BEYOND 2020

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THE OHIO STATE UNIVERSITY

CENTER FOR AUTOMOTIVE RESEARCH

June 21st, 2018

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More than **5000 researchers**

18 colleges and schools

66,000+ students across all campuses

The breadth, scope and excellence of its research programs make Ohio State a leading force of innovation and change – locally, nationally and globally.

Nearly $1B In research expenditures

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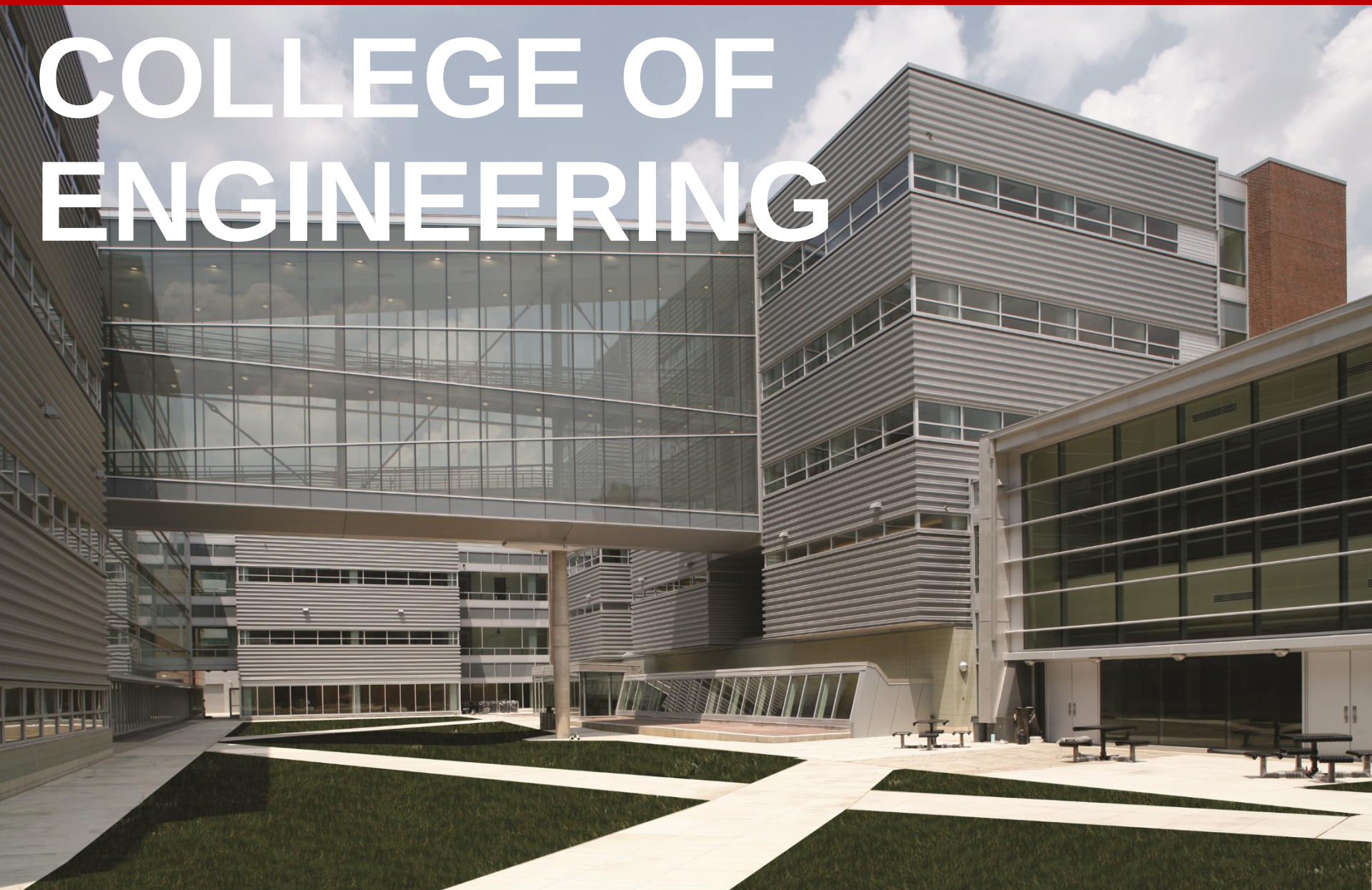

COLLEGE OF ENGINEERING

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Quick Facts

- **12 departments**
  - Biomedical Engineering
  - Center for Aviation Studies
  - Civil, Environmental and Geodetic Engineering
  - Computer Science and Engineering
  - Electrical and Computer Engineering
  - Engineering Education
  - Food, Agricultural and Biological Engineering
  - Integrated Systems Engineering
  - Knowlton School of Architecture
  - Materials Science and Engineering
  - Mechanical and Aerospace Engineering
  - William G. Lowrie Department of Chemical and Biomolecular Engineering
- 28 research centers
- 8,652 undergraduate students
- 2,047 graduate students
- 100+ student organizations

CENTER FOR AUTOMOTIVE RESEARCH

Mission

1. To provide world-class **education** for the next generation of automotive industry leaders, through on-campus learning and continuous professional development

2. To be a catalyst for **innovation** in automotive technology, through collaborative, interdisciplinary research

3. To support **economic development,** regionally and nationally

PERSONNEL 2016-2017

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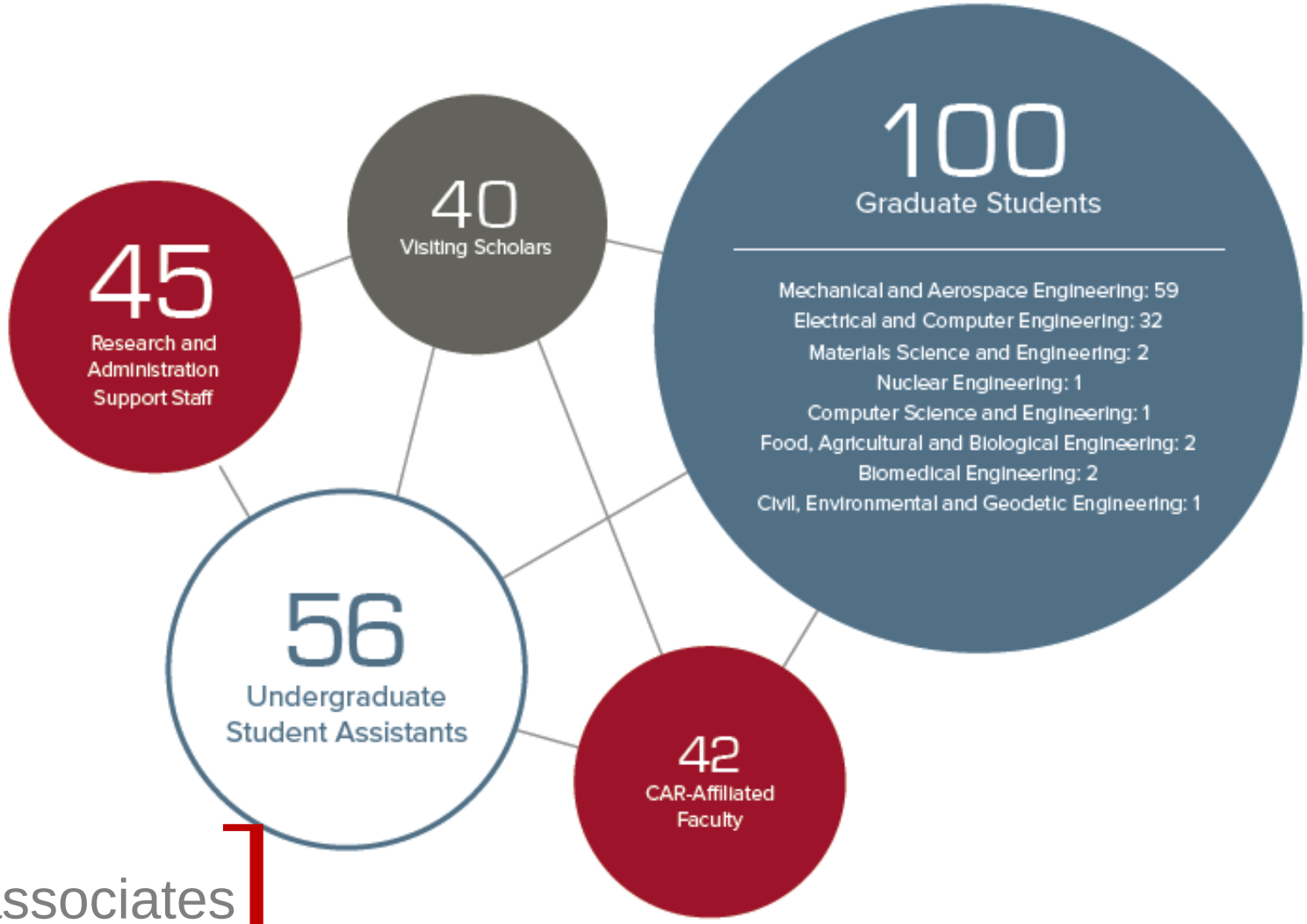

283 total associates in 2016-2017

FISCAL YEAR 2017

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TOTAL EXPENDITURES

In fiscal year 2017, CAR has secured:

$3.3 million
In industry sponsored activity

$3.5 million
In federal government-sponsored activity

$200 thousand
In state-sponsored activity

RESEARCH AND ENGINEERING SERVICES ACTIVITY

In fiscal year 2017 CAR has delivered:

$7.4 million of Research

40% Connected and Autonomous Vehicles

60% Fuel Economy

$0.6 million
of Engineering Services

$0.9 million
of Motorsports Activity

$0.3 million
of Continuing and Distance Education

MEMBERSHIP CONSORTIUM: 2018

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Platinum

FCA FIAT CHRYSLER AUTOMOBILES
Ford
HONDA
HYUNDAI
RENAULT
TRC

Gold

BOSCH
Cummins
Delphi Technologies
GM
LUK INA FAG SCHAEFFLER GROUP
MERCURY
TE connectivity
TERADATA.
TOYOTA
WIND AN INTEL COMPANY

Pending

APTIV
DANA
HCL
MAGNA
Valeo
KENWORTH
NATIONAL INSTRUMENTS
Nationwide

FACILITIES

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CAR is located on a 50,000 square foot complex on the West Campus of The Ohio State University

Advanced propulsion systems research facilities

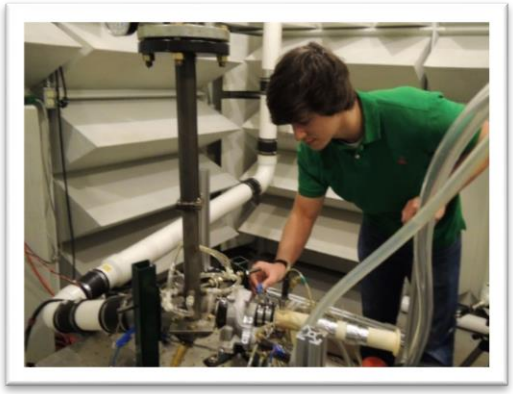
- Plug-in hybrid electric vehicle (PHEV) and hybrid electric vehicle (HEV) test beds
- Hydrogen refueling station
- Battery aging laboratory
- Battery thermal and electrochemical characterization laboratory
- Energy storage systems laboratory

Autonomous vehicle fleet

- Traffic data-collection research vehicle
- Communication and coordination research vehicle
- Vehicle-to-vehicle (V2V) and vehicle autonomy laboratories
- Driving simulator laboratory
- DENZO V2V and Embedded System Laboratory
- OSU-CITR indoor testbed

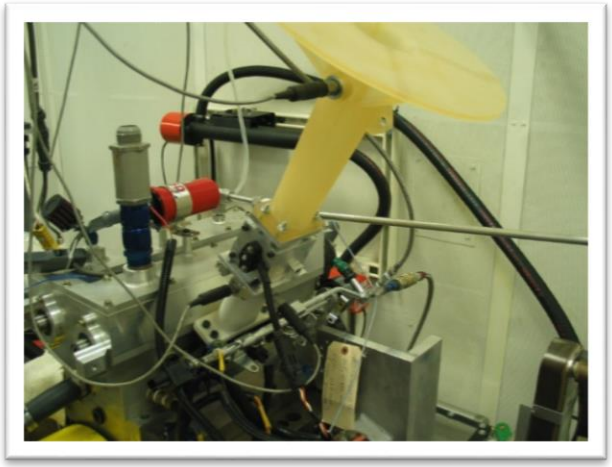
FACILITIES

Engine combustion and flow research facilities



Noise and Acoustics laboratories

- Hemi-anechoic chambers, including one with 2 chassis dynamometer



Dynamometer test cells

- Engine dynamometers (4)
- Light-duty chassis dynamometer
- Four wheel drive heavy duty chassis dynamometer

Largest independent vehicle test facility and proving grounds in the U.S.

MOTORSPORTS

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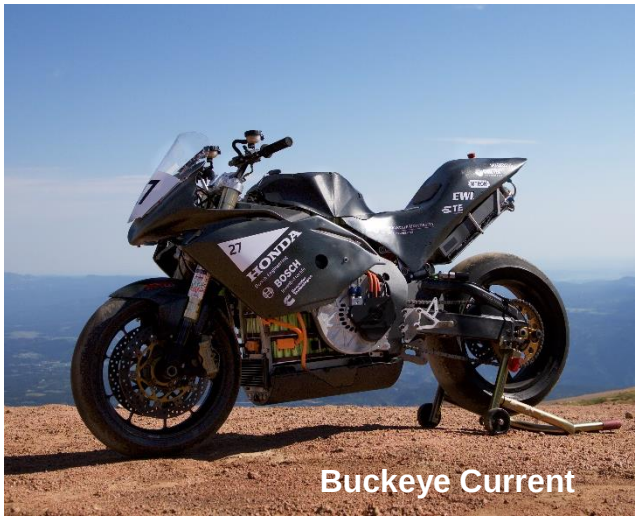
Baja SAE

Venturi Buckeye Bullet


Supermileage



Buckeye Current


EcoCAR

Formula Buckeye

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BUCKEYE CURRENT

Buckeye Current

- Fully electric motorcycle built to compete against professional race teams on both national and international stages
  - Started at the Isle of Man, moved to Pikes Peak International Hill Climb more recently
- Engineering Goals:
  - Advance technology far enough to surpass gas equivalent competitor performance
  - Give young engineers real-world automotive engineering experience
- Current competing at Pikes Peak

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OSU FORMULA SAE

FORMULA BUCKEYES

- Scaled-Down Formula-1 Style race-car that competes with hundreds of teams across America and internationally.
- Engineering Goals:
  - Improve engine performance through custom header and exhaust.
  - Hybrid carbon fiber and space frame chassis integration that will hold many benefits in manufacturing and testing time.
- We finished 13th in Michigan out of 118 teams and 3rd in Canada

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BUCKEYE BULLET

BUCKEYE BULLET

- Students desire to set a record for the fastest electric vehicle
- Engineering Goals:
  - Push the limits of electric technology beyond current applications to achieve new possibilities
- 4 Buckeye Bullets have set world records
  - Currently: 341 MPH (549km/h)

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OSU ECOCAR 3

EcoCAR 3

- 4-year Advanced Vehicle Technology Competition (AVTC) challenging 16 college teams to rebuild a 2016 Chevrolet Camaro
- Engineering Goals:
  - Increase fuel economy
  - Reduce emissions and energy consumption
  - Maintain performance and consumer acceptability

FOUR YEAR COMPETITION

Year One: 0 Buyoff

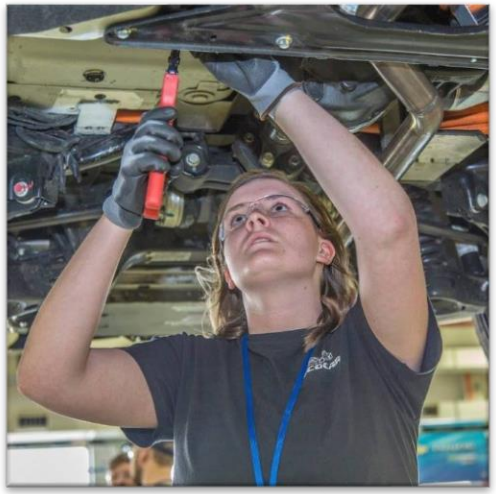
- Design the car
  - Choose engine, transmission, other key components

Year Two: 50% Buyoff

- Build the car
  - Received car in December 2015
  - Had three months to completely rebuild as a hybrid vehicle

Year Three: 65% Buyoff

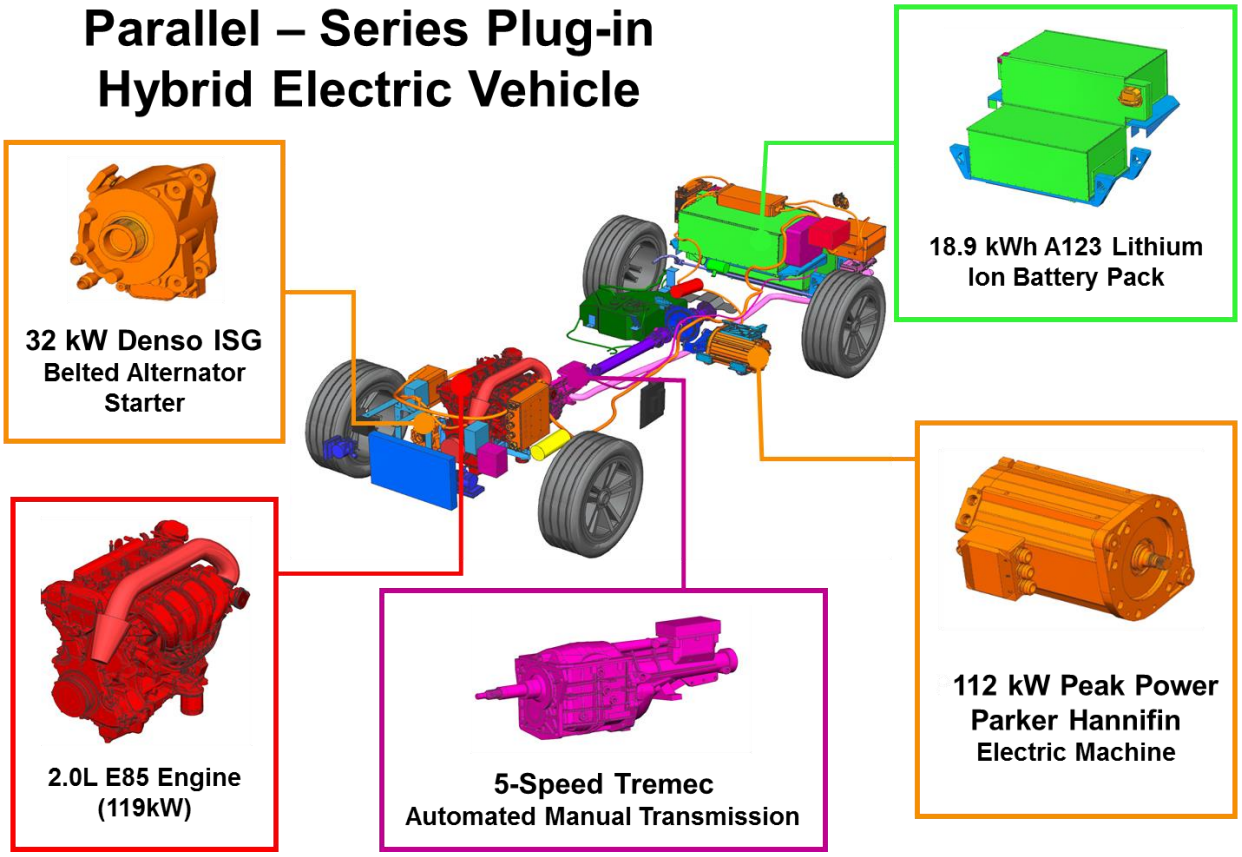
- Refine the car
  - Work out all bugs and problems in car
  - Begin to tweak vehicle and its systems to achieve maximum performance and efficiency
  - Test emissions and energy usage



Year Four: 99% Buyoff

- Refine and Optimize the car (cont.)
  - Ensure car drives and feels as good as one just bought from a showroom
  - Tweak vehicle and its systems to achieve maximum performance and efficiency

Vehicle Architecture

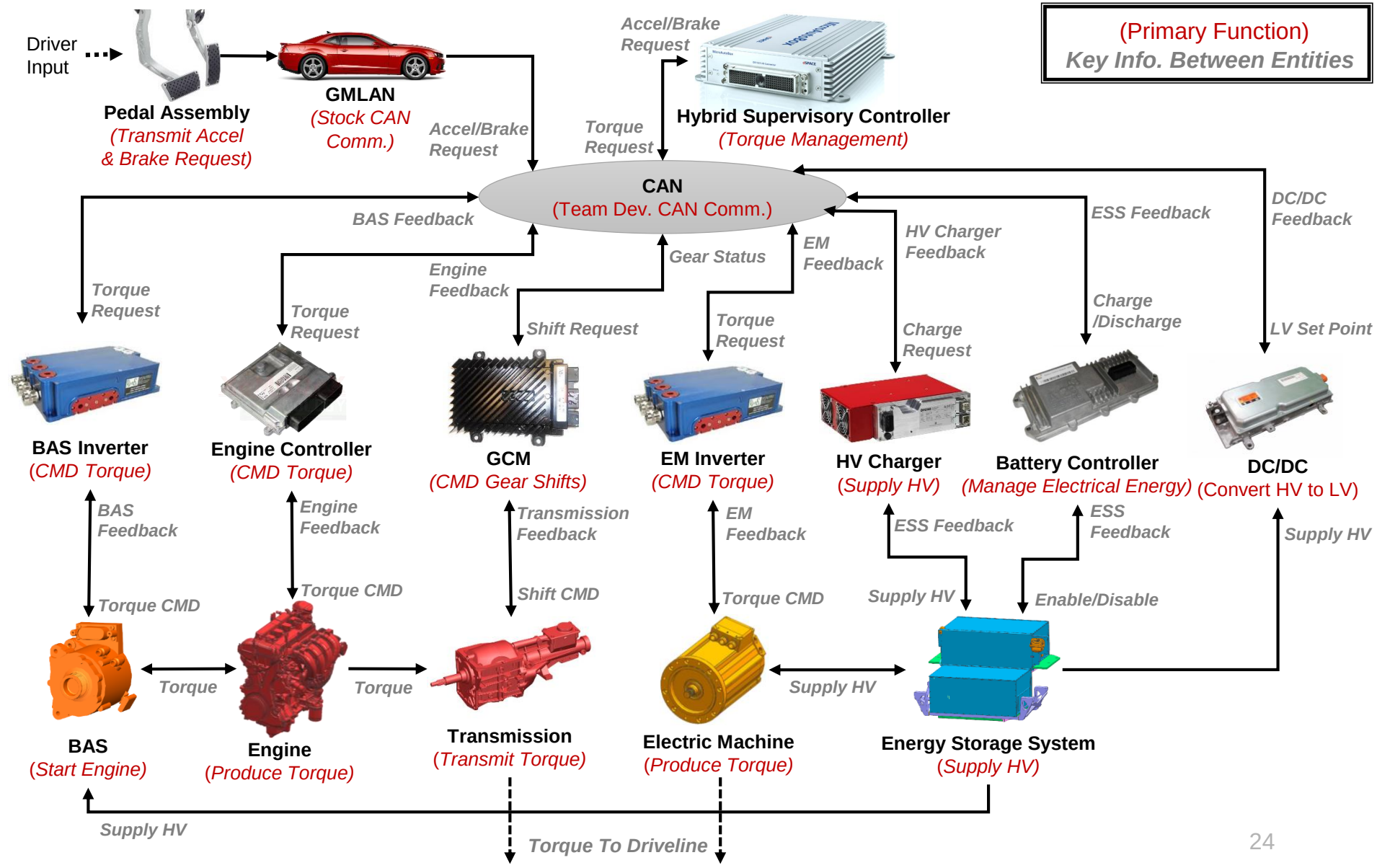


Unique Feature

- 40 mile EV range
- 40 MPGge
- EHC providing 85% cold start emissions reduction
- AMT featuring magnetic position sensing
- ADAS system displaying safety warnings and improving fuel economy

Controls Architecture

(Primary Function)
Key Info. Between Entities



Controls Architecture

Team Developed Controllers

Hybrid Supervisory Controller

- Torque Split
- Shift Logic
- Low-Level Shift Control
- ADAS & Driver Controls
- Connectivity App Controls
- CAN Bridging
- Hybrid Operating Mode
- Active Rev Matching
- Fault Detection
- Fault Mitigation Strategy
- Drivability Management
- Start up and Shutdown Management
- Data Recording
- Charging Management
- Engine Thermal Management
- Electronic Thermal Management
- ESS Thermal Management
- Electrically Heated Catalyst Controls

General Control Module

- Electrical Actuation
- Signal Processing

Engine Controller

- Air Fuel Ratio (AFR) Calibration

Algorithm Modeling and Simulation

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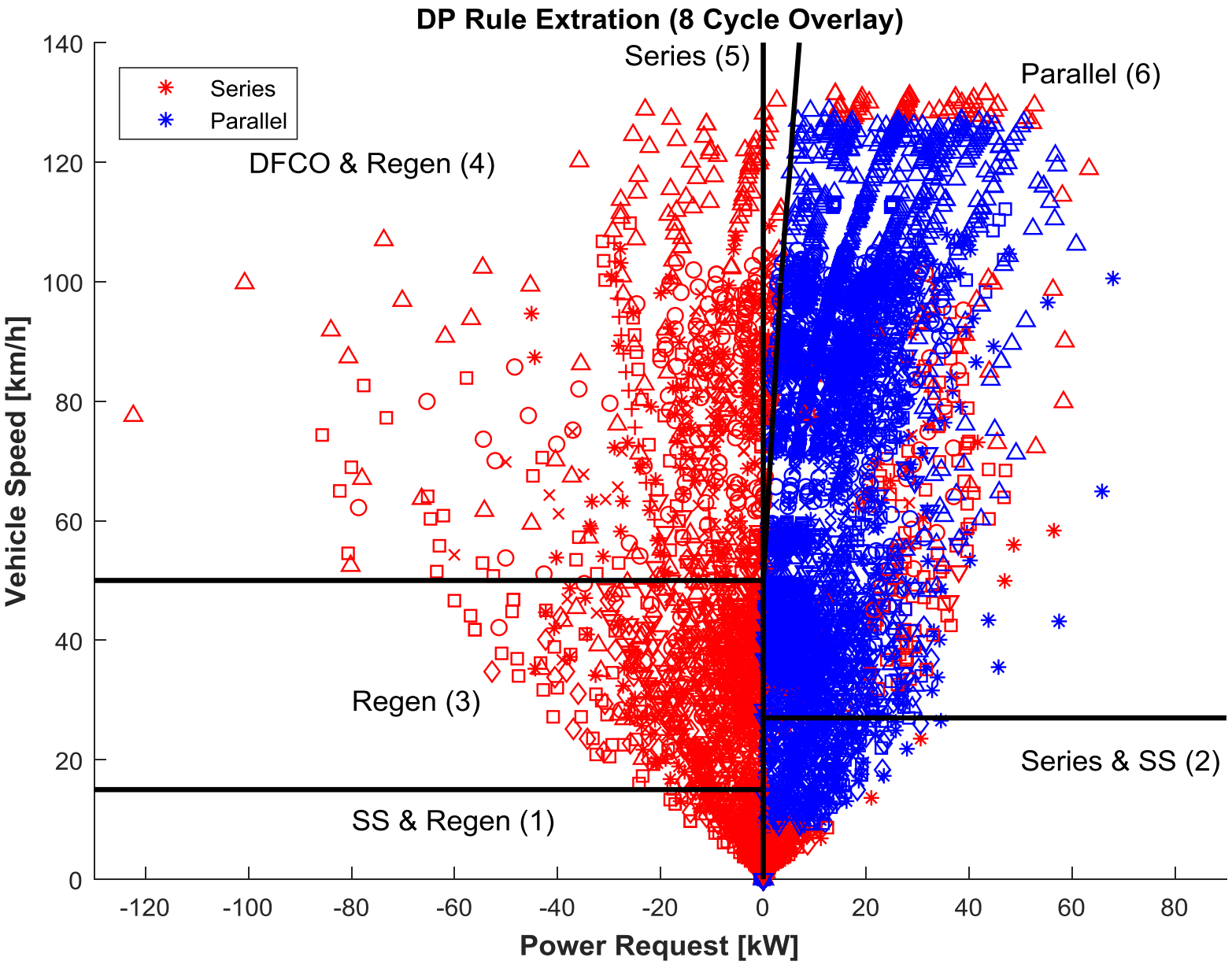
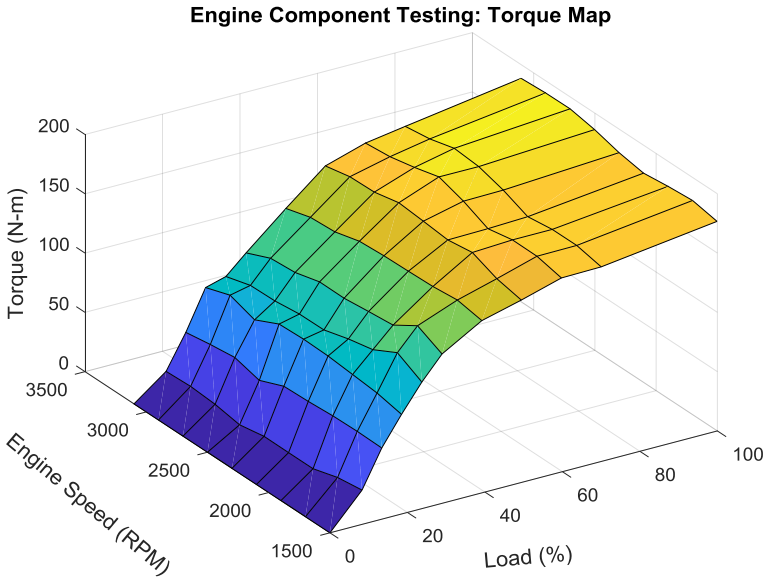
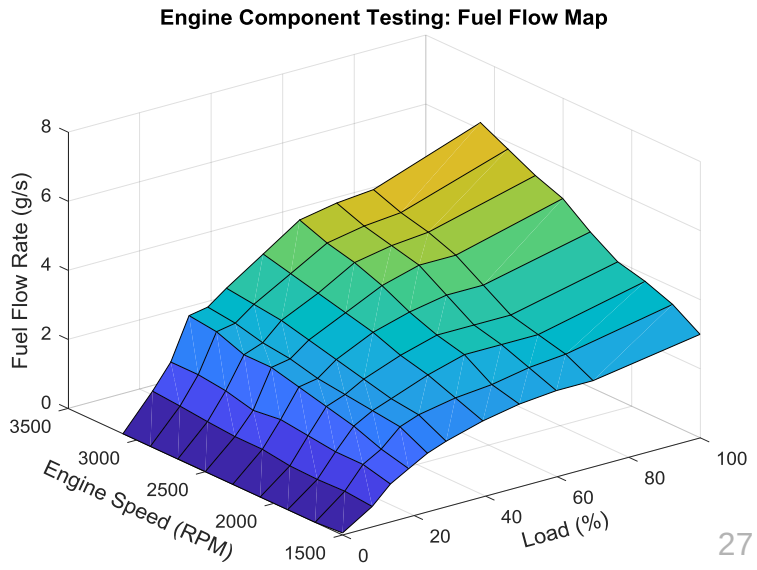


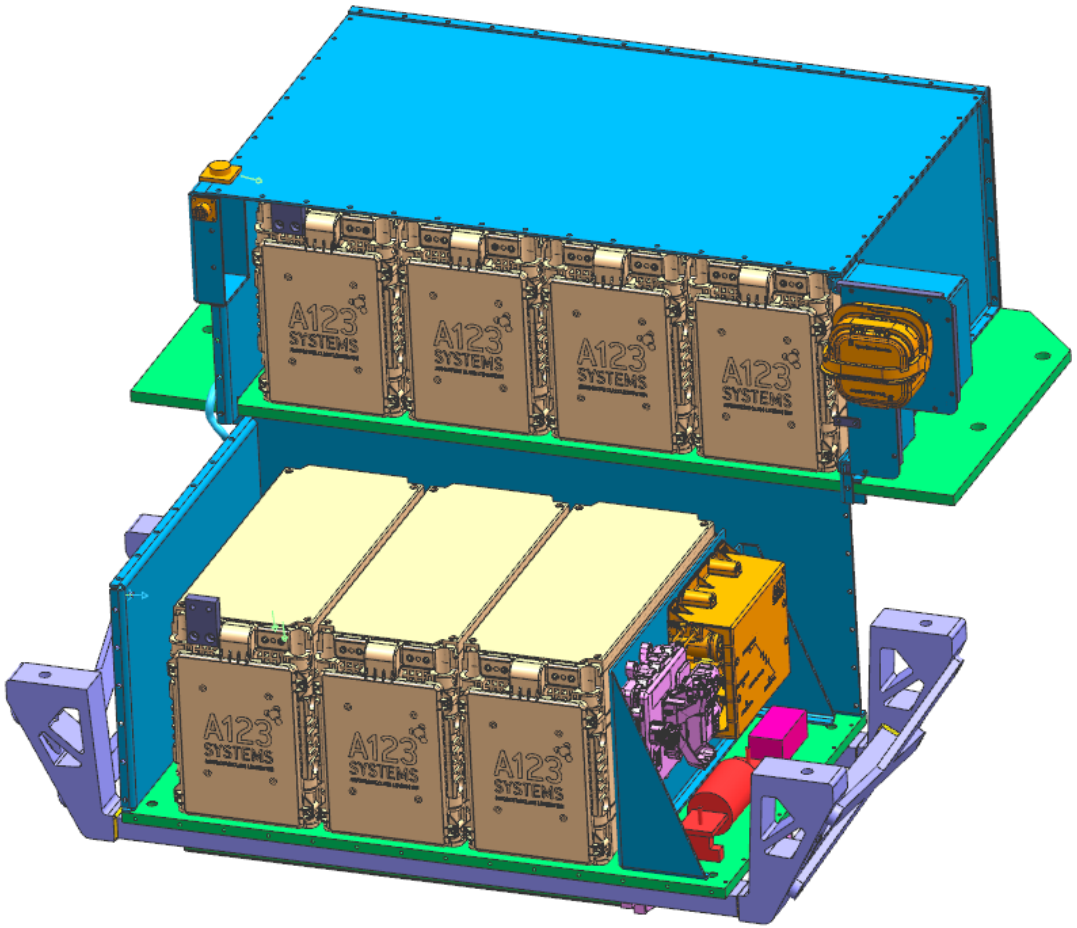
Model Improvement to Support xIL V/V

- Large engine DOE:
  - Goal:
    - Torque map
    - Fuel map
    - Efficiency map
    - Lambda validation
  - Execution:
    - Swept 1500-3000 RPM, 0-100% Load
    - Recorded fuel in, power out, lambda, etc.
- Enabled torque estimation needed for DP torque split
- Provided detailed experimental engine maps
- Average fuel correction: **3.8%**
- Average torque correction: **6.6%**





Hardware Packaging



Upper Group

Battery Modules

Base Plate and Cooling Fins

Manual Service Disconnect

High Voltage Connector

Battery Module Housing

Lower Group

Battery Modules

Base Plate and Cooling Fins

Current Sense Module

Electronic Distribution Module

CSM and EDM Support

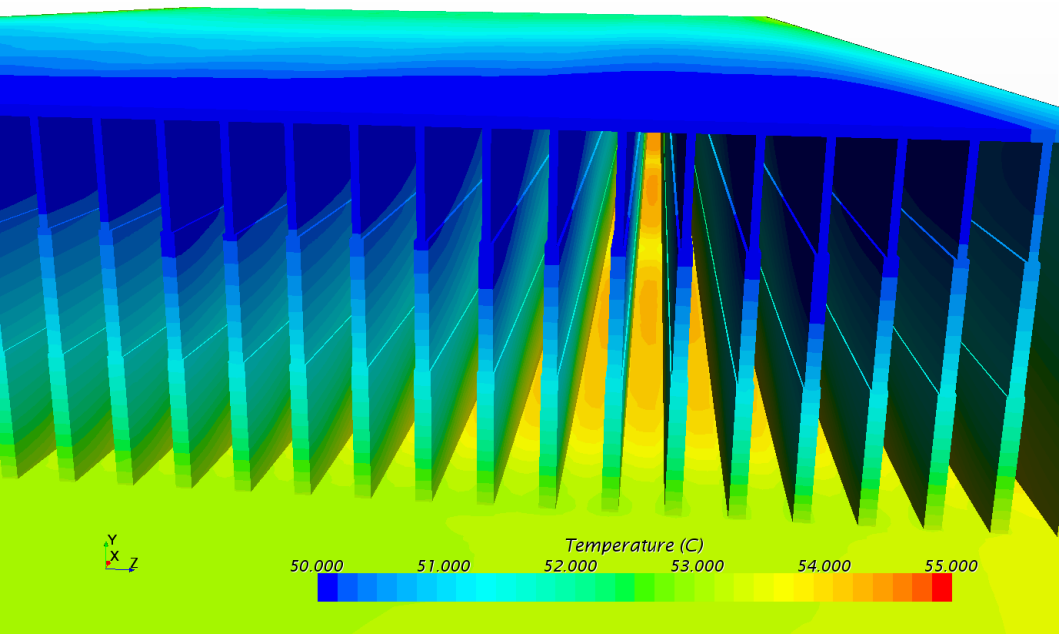
HV Fuse

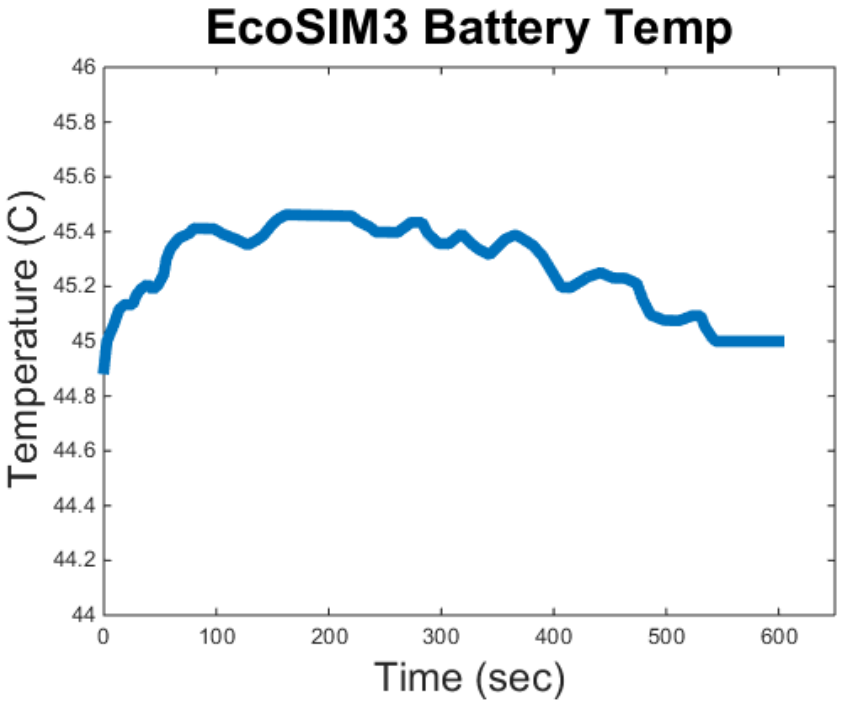
LV Fuse holder

Mounting Structure

ESS Simulated Testing

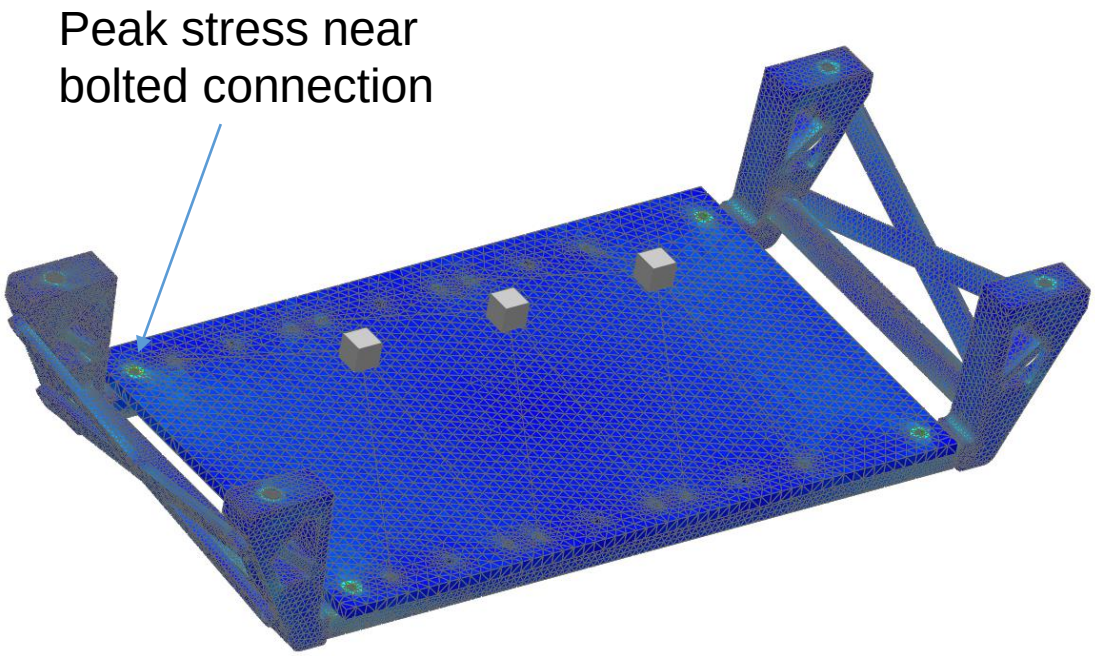
- Adequate cooling validated through CFD on Star-CCM
- Safe vehicle operation at 45°C ambient for US06
  - Modeled by SMS team and validated from previous EcoCAR 2 design





Structural Supports – Lower Group

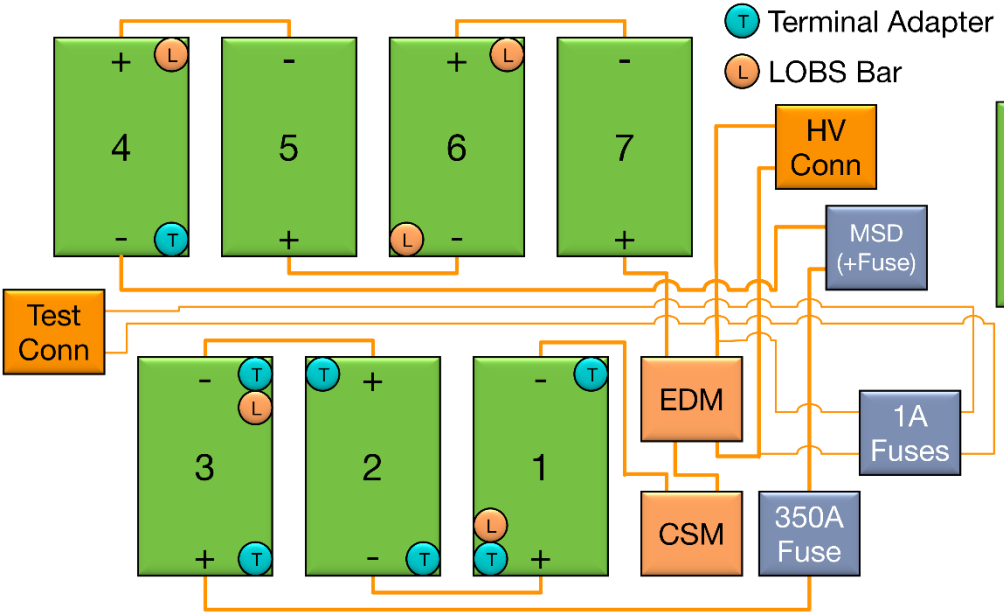
- Aluminum cradle bolted to rigid body (frame rails)
- Modules represented as a point mass rigidly connected to the bolt locations
- Peak stress value is an artifact of the rigid bolted connection



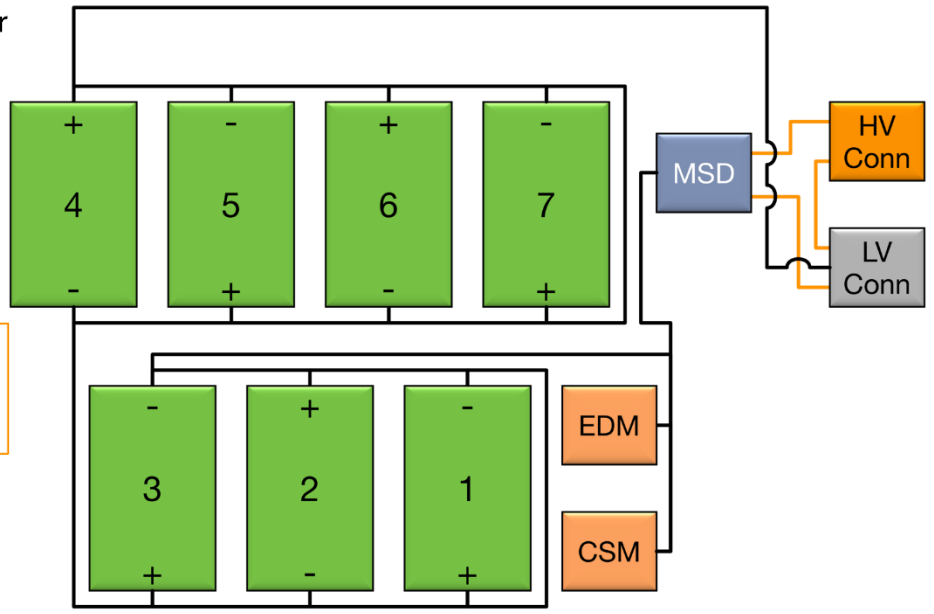
Load Case	Max Stress (Mpa)	Factor of Safety
20g Forward	144	1.67
20g Rear	141	1.71
20g Right	145	1.66
20g Left	147	1.63
8g Up	33	7.30
8g Down	42	5.73

LV and HV Wire Routing

High Voltage Routing



Low Voltage Routing



- 1, 2, and 3 are the lower pack
- 4, 5, 6, and 7 are the upper pack

ESS Final Integration

Commitment to Outreach

- Welcomed over 1500 guests during the past fiscal year
- Hosted numerous outreach events
- Partnership with the PAST Foundation, focused on K-12 outreach

PERSONAL MOBILITY BEYOND 2020

GIORGIO RIZZONI

THE FORD MOTOR COMPANY CHAIR IN ELECTROMECHANICAL SYSTEMS

PROFESSOR,
MECHANICAL AND AEROSPACE AND ELECTRICAL AND COMPUTER ENGINEERING

DIRECTOR
CENTER FOR AUTOMOTIVE RESEARCH

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MOBILITY AGENDA

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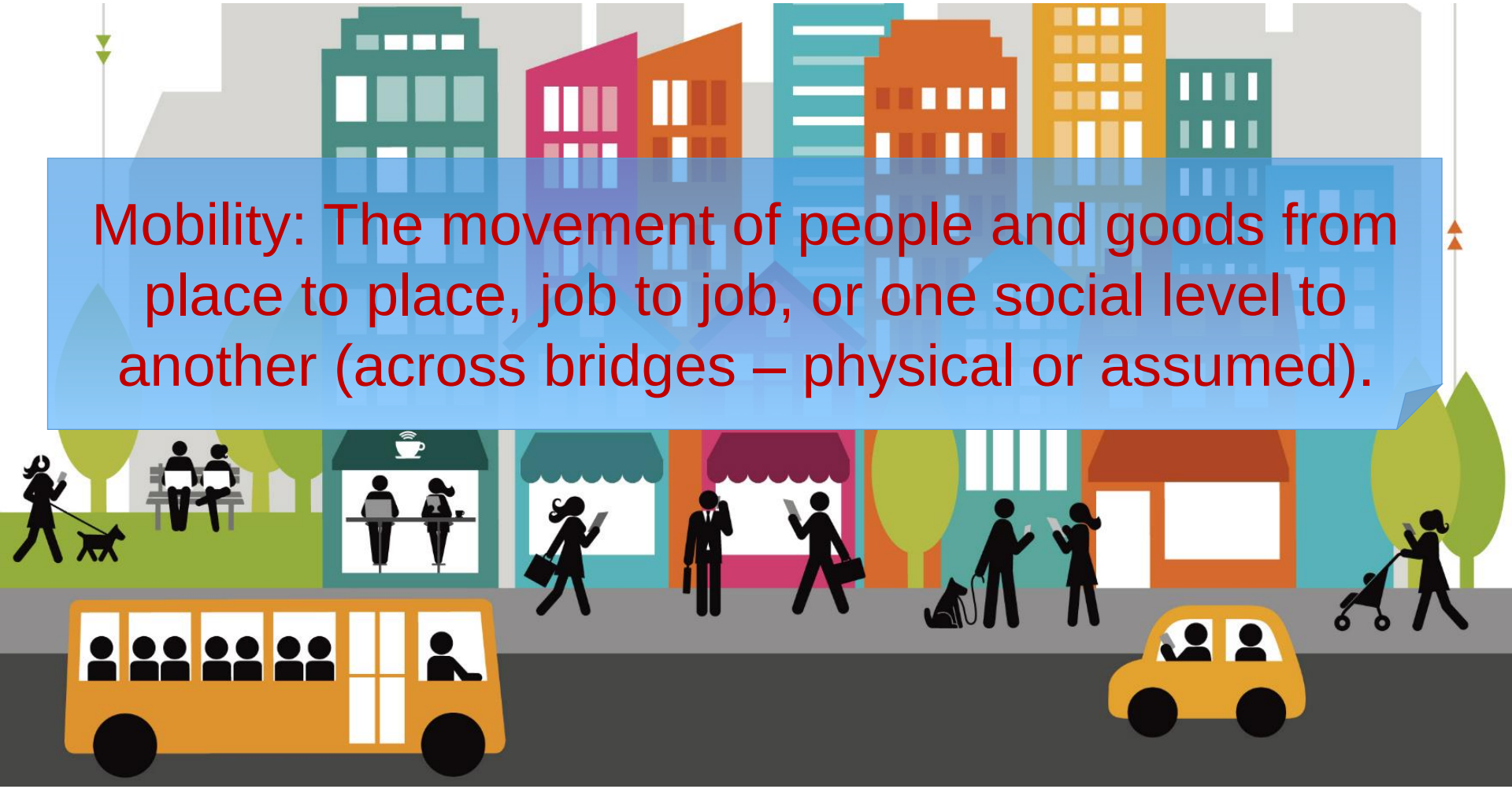
- Mobility is essential to a productive society
- Energy is a necessary part of mobility
- Congestion and urbanization are changing the way we think about mobility
- How will this translate into new business and technology development models?



Mobility: The movement of people and goods from place to place, job to job, or one social level to another (across bridges – physical or assumed).

UNITED STATES' ENERGY USE IN 2016

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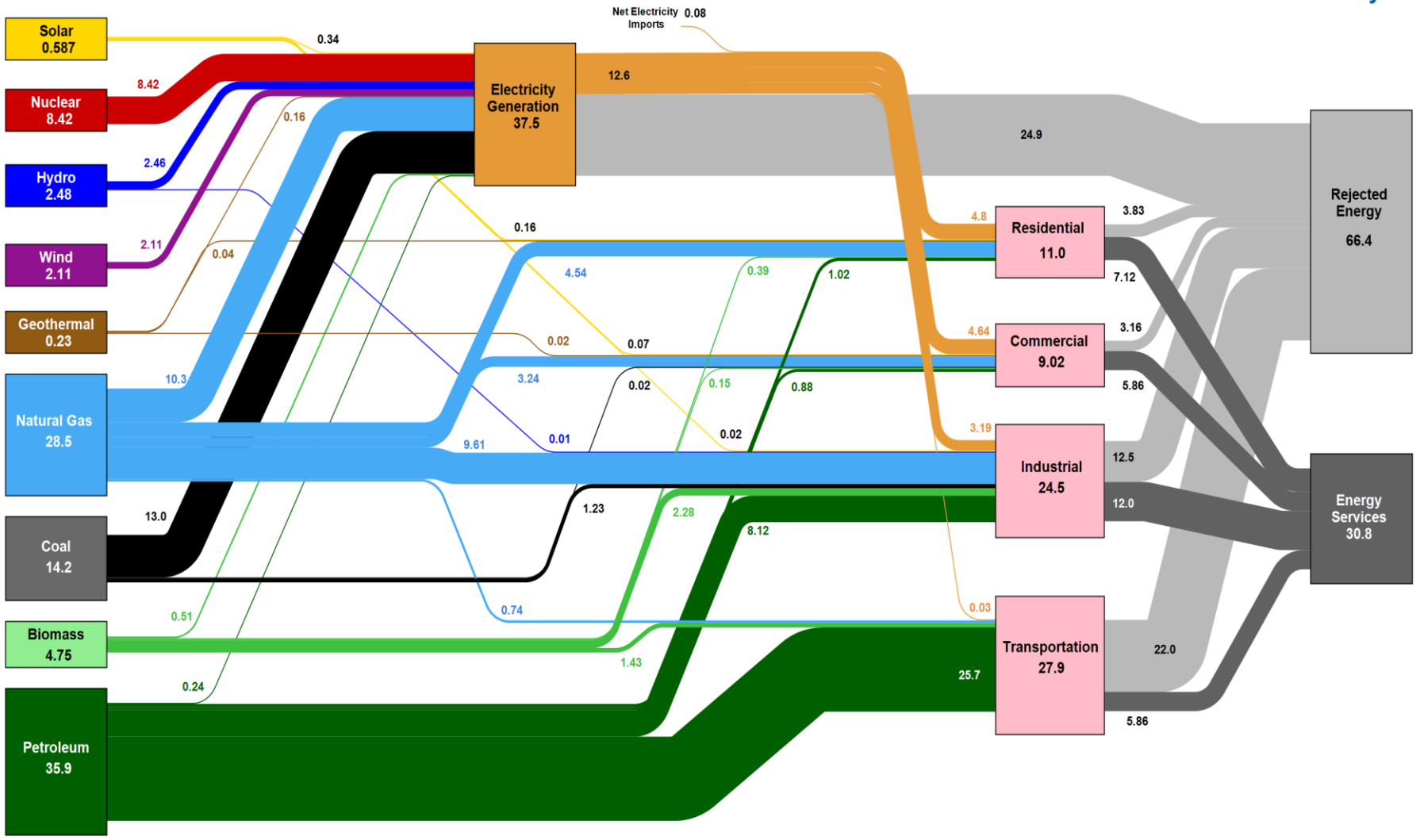
Estimated U.S. Energy Consumption in 2016: 97.3 Quads

Lawrence Livermore National Laboratory



Source: LLNL March, 2017. Data is based on DOE/EIA MER (2016). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

URBANIZATION AND CONGESTION

How many cars do you think are in circulation today, worldwide?

2 BILLION CARS!



Today, there are 1 billion cars on the road.
Can we sustain a 2 billion car world?

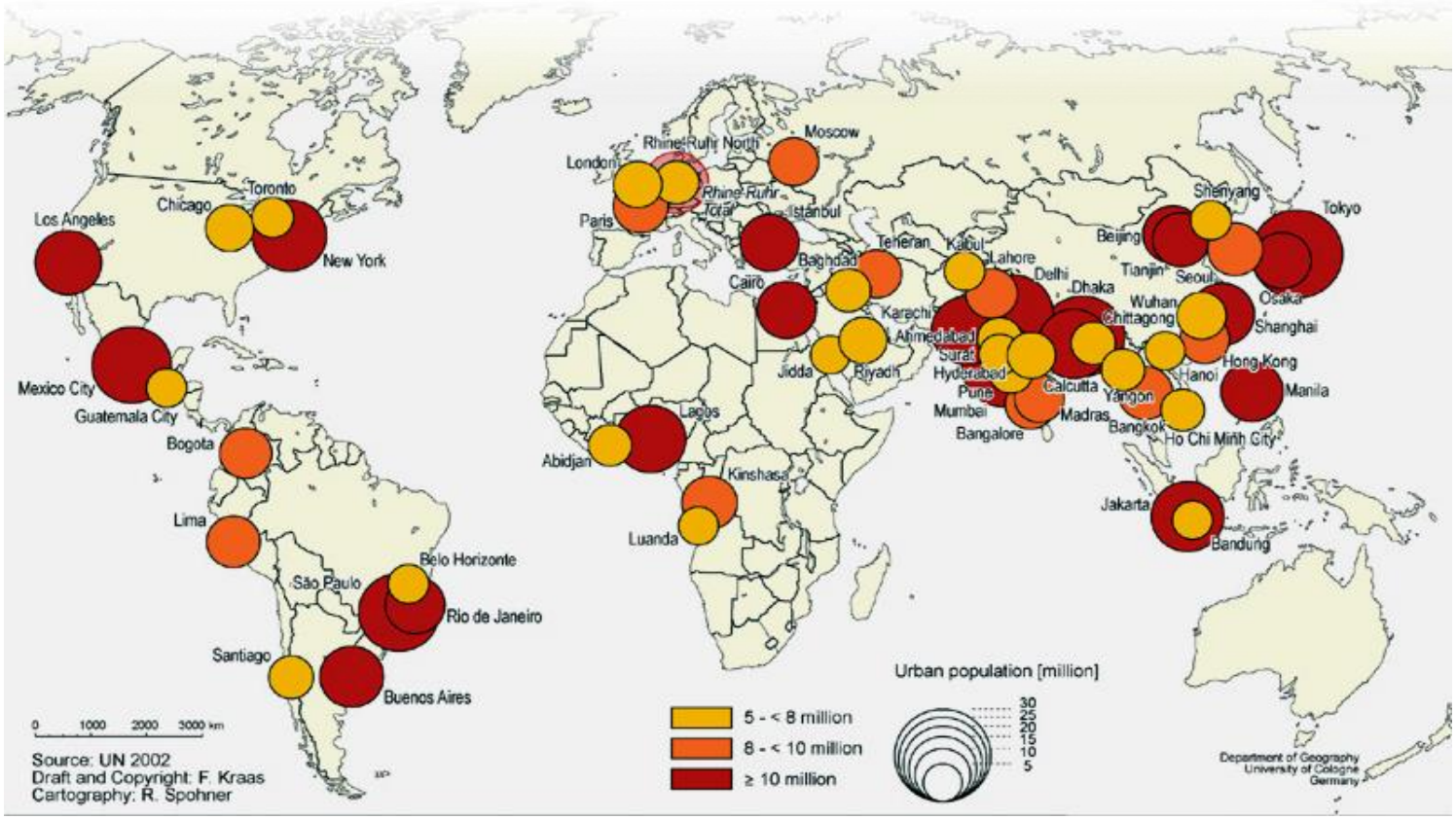


A NEW CHALLENGE: CONGESTION!

1917 football parking, The Ohio State University Archives

MEGACITIES!

By 2030, 60% of the world's population will live in urban areas, up from 50% today (70% by 2050). Within 20 years, 80% of wealth will be concentrated in cities. As the urban population increases, traffic congestion in large metro areas will become an even bigger issue.



REDUCING VEHICLE MILES TRAVELED?

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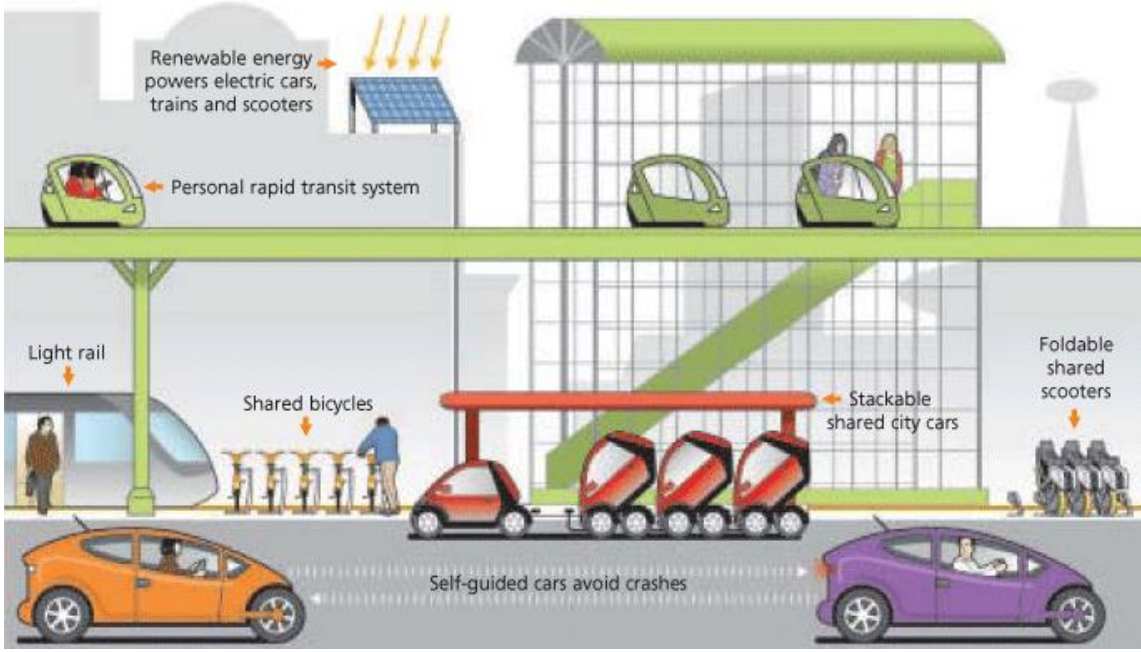
URBAN MOBILITY

Over the next decades, all of the world's population growth will be in urban areas, with Asia and Africa accounting for 90% of the growth

- By 2030, urban areas are projected to account for 60% of the population and greater than 80% of the wealth

Implications for transportation systems

- **Personal** vs. mass transportation
- Car sharing
- Low-/zero-emission capability
- Growth of urban vehicles to cope with parking problems
- Increasing use of information systems
- And, of course, telecommuting and virtual presence



SMART CITIES, SMART COMMUNITIES

DOWNTOWN DISTRICT

#SMARTCOLUMBUS

Delivery Zone Availability

Enhanced Permit Parking

Parking Management

COMMERCIAL DISTRICT

#SMARTCOLUMBUS

Connected Electric Automated Vehicle

TOMORROW'S MOBILITY?

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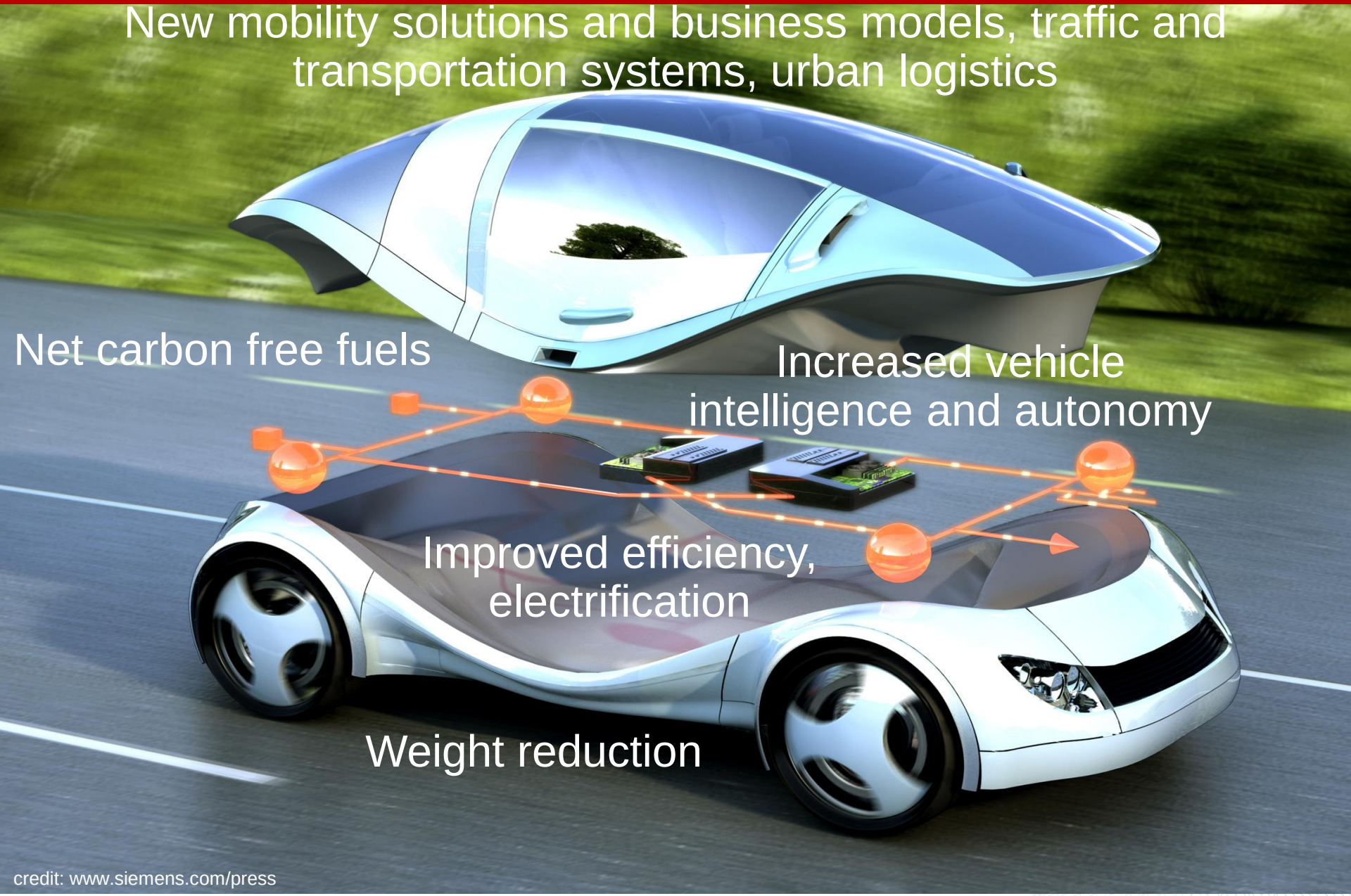

credit: www.siemens.com/press

PERSONAL MOBILITY TOMORROW…
EVERYTHING OLD IS NEW AGAIN

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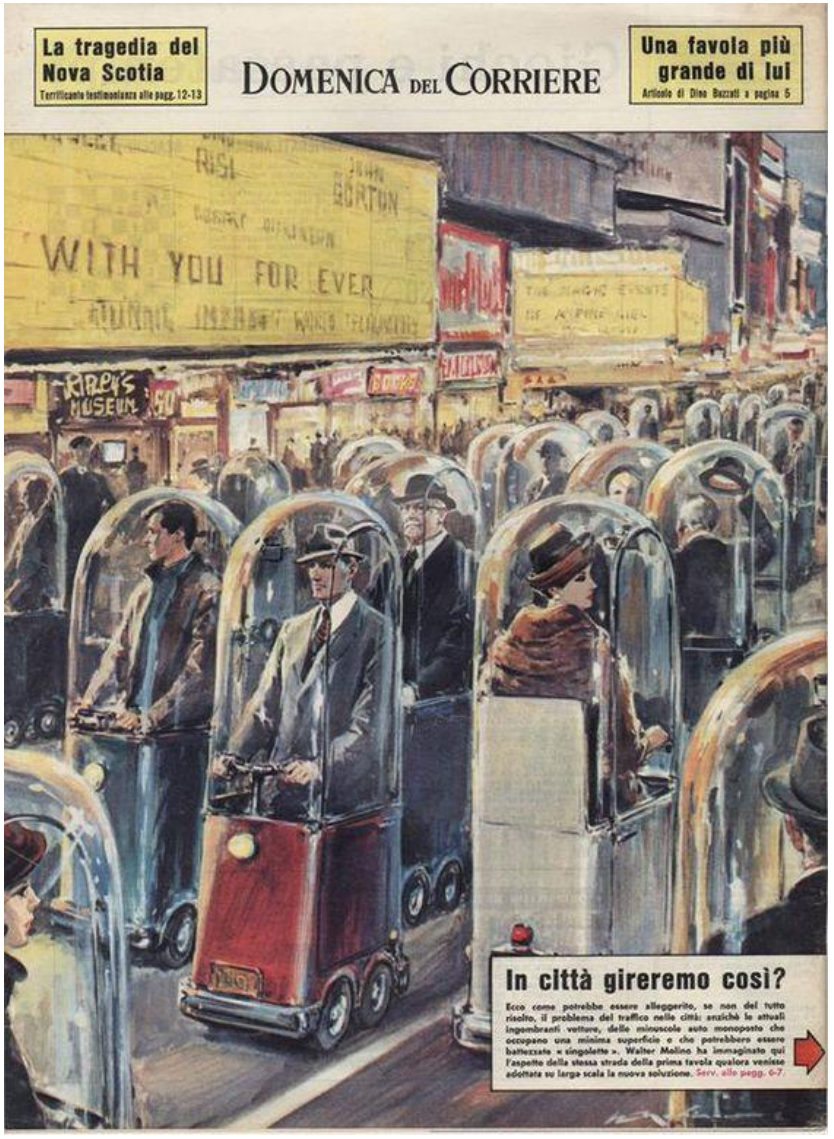

THANK YOU
QUESTIONS?

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