U.S.–China Clean Energy Research Center
中美清洁能源研究中心
Clean Vehicles Consortium

U.S.-China Clean Energy Research Center Clean Vehicles Consortium (CVC)

Report to Steering Committee

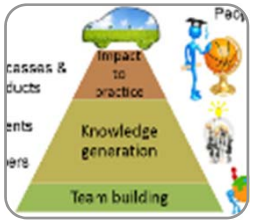
OUYANG Minggao (China Director, Tsinghua University)

Huei Peng (US Director, University of Michigan)

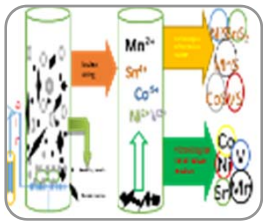
June 1, 2015

Outline

Summary of CVC 1.0



Final Year of CVC 1.0



Next Plan for CVC 2.0

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CERC Steering Committee Guidance

- *"Be Ambitious, Creative and Bold;*
- *Broaden Participation Among Research Performers;*
- *Strengthen Engagement with Existing Industrial Partners and Recruit New Partners;*
- *Concentrate on Selective Areas with High Payoff;*
- *Enhance Research Quality and Impact of Selected Projects;*
- *Leverage Platforms and Resources of Others; and*
- *Develop and Show Roadmaps that Will Achieve Public Benefits in Both Countries with Milestones to 2020."*

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CERC-CVC Thrust Areas

1. Advanced Batteries System

2. Advanced Biofuels, Clean Combustion and APU

3. Vehicle Electrification

4. Lightweight Structures

5. Vehicle-Grid Integration

6. Energy Systems Analysis, Technology Roadmaps and Policies

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Consortium Overview

Academic & National Lab Partners

U.S.

University of Michigan

The Ohio State University

MIT Massachusetts Institute of Technology

Sandia National Laboratories

Oak Ridge National Laboratory

Argonne National Laboratory

jbei Joint BioEnergy Institute

China

Tsinghua University

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Consortium Overview

Industrial Partners

U.S.

Ford, DELPHI, DENSO, EATON, TOYOTA, HONDA, pjm, TE connectivity, Aramco Services Company

China

SAIC, GEELY, JAC, CAERI, CATARC, 上汽通用五菱 SGMW, LISHEN, Potevio, JJE, ECTEK, KeyPower 科易动力

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Organization

Director:
Huei Peng

Deputy Director:
Jun Ni

Director:
OUYANG Minggao

Deputy Director:
Wang Hewu

Deputy Director:
Qiu Xinping

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CVC-Annual Tech. Meetings

Kick-off meeting, Michigan, Jan 2011

1st annual meeting, Beijing, Oct 2011

2nd annual meeting, Michigan, Aug 2012

3rd annual meeting, Beijing, Aug 2013

4th annual meeting, Michigan, Aug 2014

5th annual meeting, Beijing, Aug.17-18, 2015 (Upcoming)

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US-China Electric Vehicle and Battery Workshop

- 1st:Sept. 2009 in Beijing, China
- 2nd:Sept. 2010 in Chicago, USA
- 3rd:March 2011 in Beijing, China
- 4th:Aug. 2011 in Chicago, USA
- 5th:April 2012 in Hangzhou, China
- 6th:Aug. 2012 in Boston, USA
- 7th:April 2013 in Berkeley, USA
- 8th:Sept. 2013 in Chengdu, China
- 9th: Aug. 2014 in Seattle, USA
- 10th: March 2015 in Beijing, China

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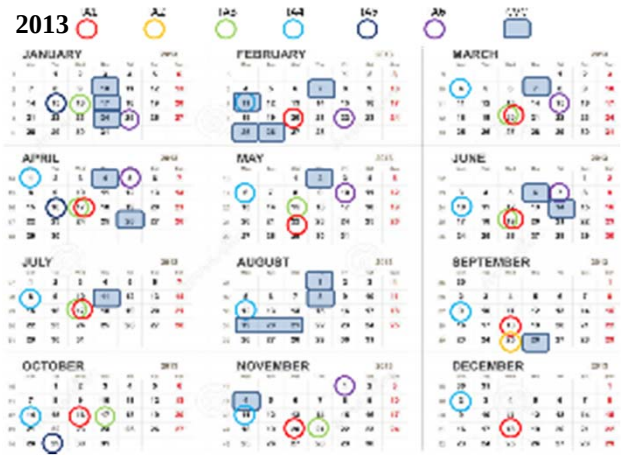
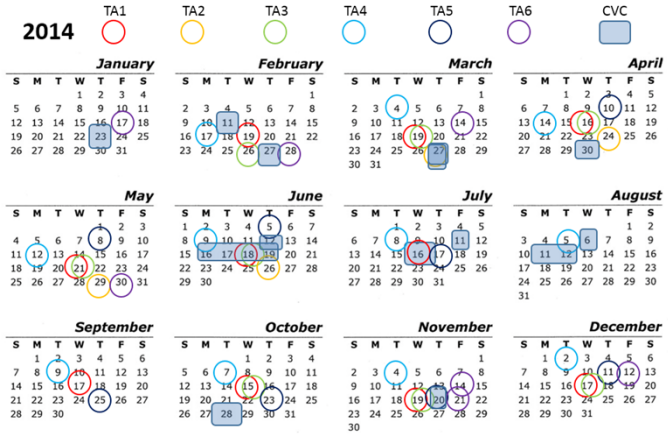
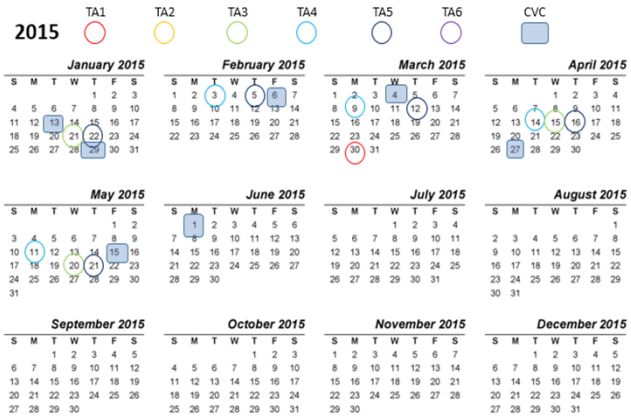
Technical Conference Calls

Web-meetings in 2012-2015 (mostly by individual TA)







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Personnel Exchange

Name	Status	TA	Date
Caihao Wang	Ph.D. (UM)	TA2	05/11-06/11
Xiankun Huang	Ph.D. (THU)	TA1	07/11-08/12
Xiaowu Zhang	Ph.D. (UM)	TA2	06/12-06/12
Xuerei Ma	Ph.D. (SJTU)	TA2	12/12-12/13
Mingxuan Zhang	Ph.D. (THU)	TA2	01/13-02/13
Cong Hou	Ph.D. (THU)	TA2	06/13-08/13
Yugong Luo	Prof. (THU)	TA5	08/13-08/14
Xuning Feng	Ph.D. (THU)	TA3	12/13-12/14
Tze-You Song	Ph.D. (THU)	TA1	12/13-12/14
Tanjin He	Ph.D. (THU)	TA2	01/14-06/14
Lin-Jun Song	Prof. (BHU)	TA6	06/13-06/14
Yong Xia	Prof. (THU)	TA4	
Han Hao	Prof. (THU)	TA6	
Xiaobin Zhang	Ph.D. (THU)	TA6	

Performance Metrics

- Joint conferences, workshops and symposia organized
  - 5 CERC-CVC-wide meetings, 10 EVI workshops
  - ~50 meetings per year (mostly by individual TA)
- Journal and conference papers published
  - >350 papers published or accepted, joint 20 papers
- IP disclosures filed; US, China, and international patents issued
  - 71 in China, 28 in US (20 from Chinese side)
- Number, frequency, duration of personnel exchanged/collocated among organizations
  - ~ 100 short-term visits, 30 long-term (> 30 days) visits planned or executed

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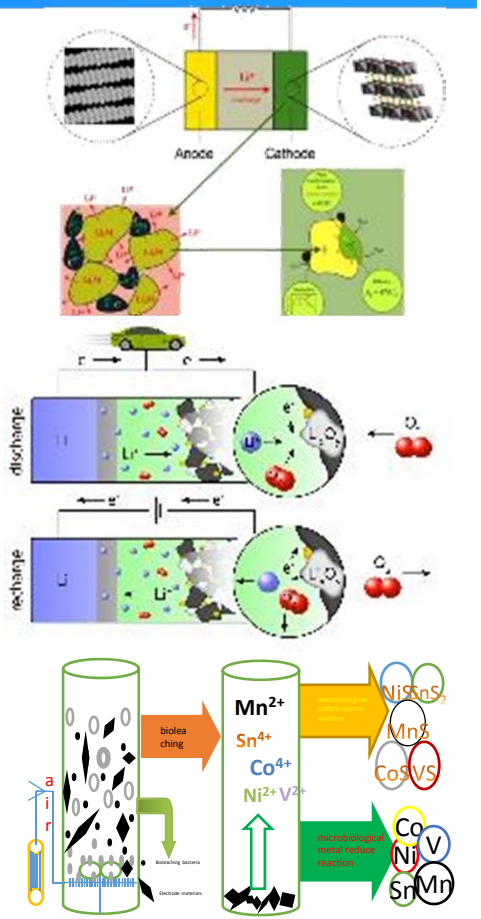
Thrust 1: Advanced Batteries System

- **Degradation**: Combine modeling and advanced characterization to understand degradation mechanisms in Li-ion batteries.
- **Modeling, Controls, and Implementation**: To extend battery life, develop battery management systems with on-board balancing technologies.
- **New Chemistries**: Advance Li-air and Li-sulfur chemistries towards commercial viability by revealing limiting phenomena and developing materials/architectures that overcome these obstacles.
- **Battery testing standards**: Review protocols for battery testing & safety.
- **Battery reuse & recycle**: Explore pathways for reuse & recycling of batteries.



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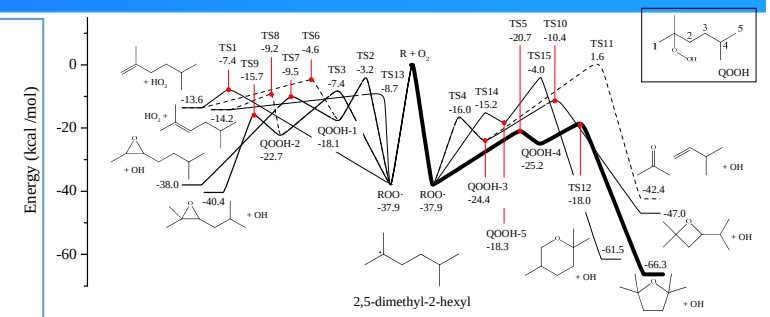
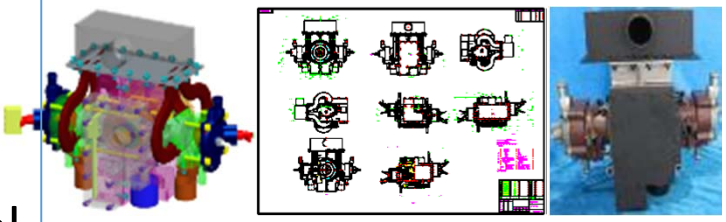
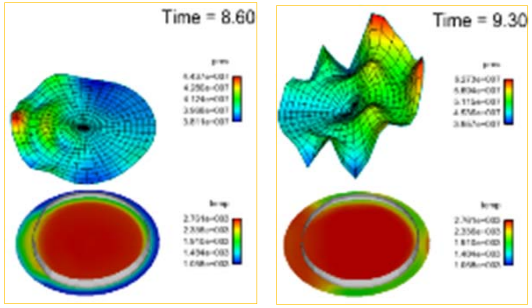
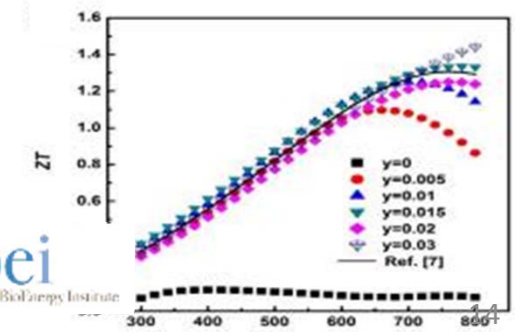
Thrust 2: Advanced Biofuels, Clean Combustion and APU

- **Biofuels**: Collaborative computational and experimental study of cellulosic biofuels produced using microbial synthesis.
- **APU Engines**: Challenges and opportunities of range-extender engines.
- **Integration of Powertrain and Aftertreatment**: Holistic consideration of fuel property, combustion modes, after-treatment systems, and hybrid powertrains.
- **Novel Thermoelectric Materials**: Develop highly efficient TE materials with high figure of merit, and the synthesis methods.









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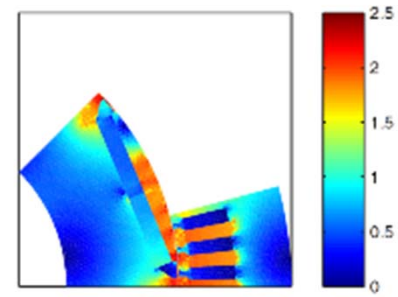
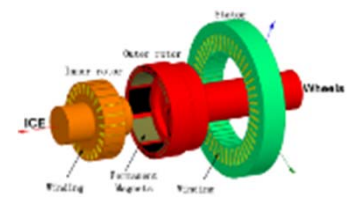
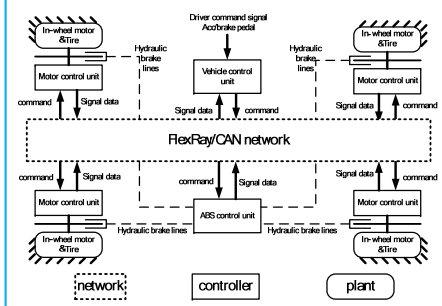
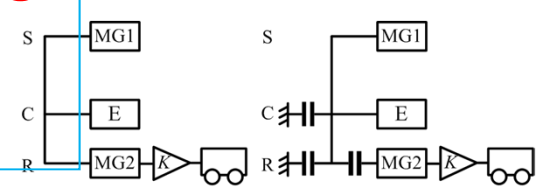
Thrust 3: Traction motor and control system

- **Components Design and Optimization**: Develop models for fast and accurate design and optimization of motors and power electronics.
- **Powertrain and Distributed Vehicle Control Networks**: To study critical communication and control issues of electrified vehicles.
- **System Integration Technologies**: Models, sizing and control for efficient hybrid vehicle powertrain development.
- **Data Drive Battery Modeling and Health Monitoring**: Model driven battery management systems.









(a) The original Prius (b) The Prius++

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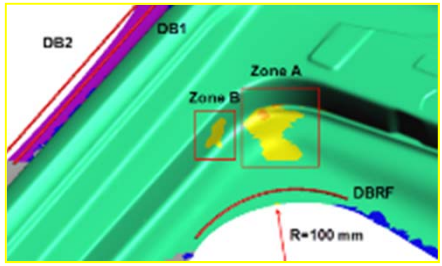
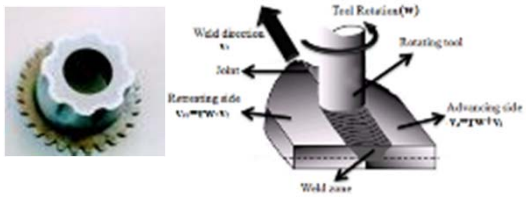
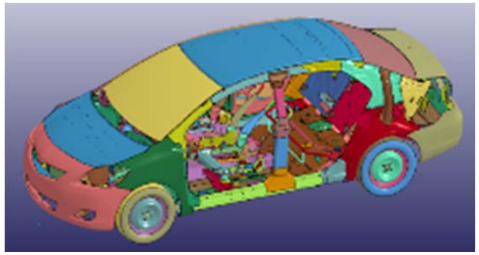
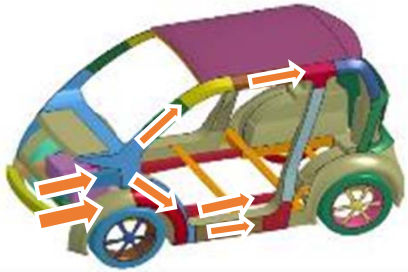
Thrust 4: Lightweight and crash safe of EV

- **Manufacturing processes of lightweight body**: Low-cost, energy efficient, and high quality processes for bulk forming lightweight materials and joining dissimilar lightweight materials.
- **Design of EV with lightweight structure**: Guidelines, tools, and methods for optimally integrating lightweight components into vehicle structures utilizing the developed forming and joining processes.
- **Crash safety of lightweight EV**: Experimental and computational methods for evaluating crashworthiness of components and assemblies made of lightweight materials.









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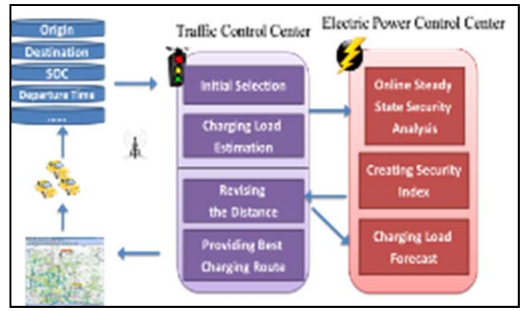
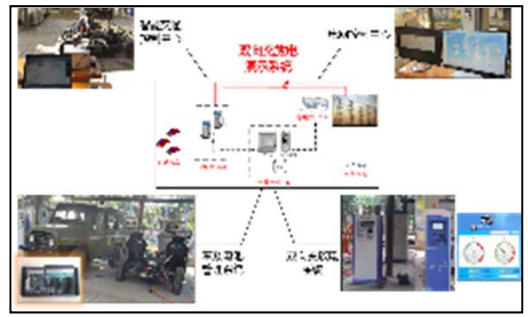
Thrust 5: Vehicle-Grid Integration

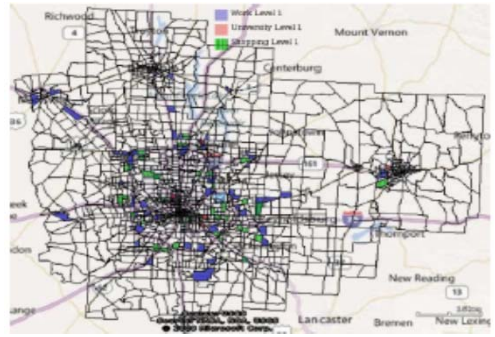
- **Vehicle-Grid Interaction**: Assess the impact of large-scale deployment of PEVs on the grid and develop technology and policy recommendations to accelerate EV deployment in the U.S. and China.
- **Vehicle-Grid Integration**: Develop control strategies and protocols for vehicle-grid interactions.
- **Information Grid**: Use of Intelligent Transportation Systems technology to optimize vehicle charging infrastructure and energy use.



Smart Charging Guiding System (SCGS)



EV-RES Coordination



Charging infrastructure design

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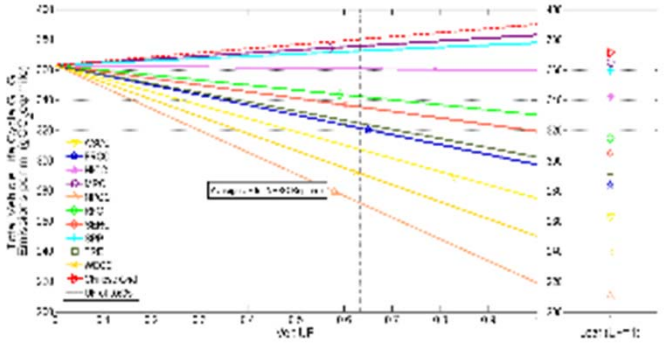
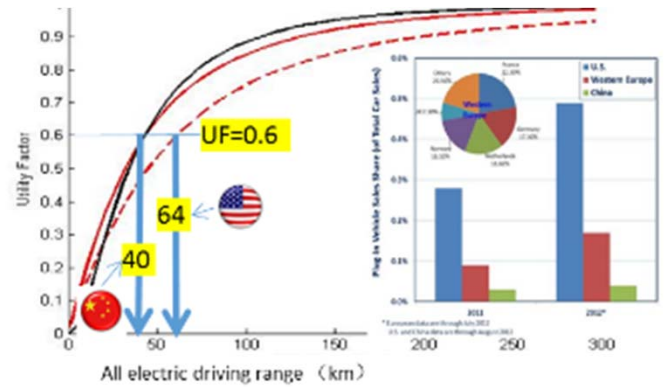
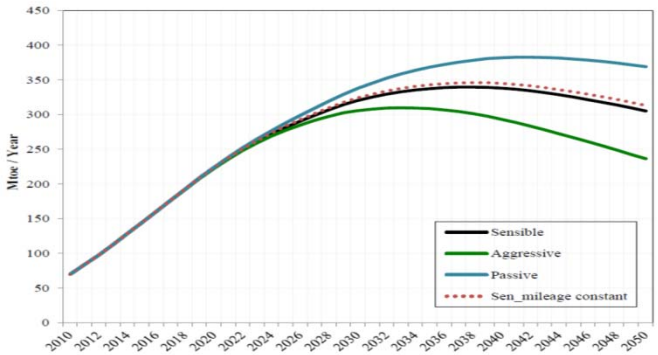
Thrust 6: Energy and system analysis of EV

- **Life Cycle Analysis**: Develop EV energy efficiency, carbon targets and evaluate life cycle performance of EV powertrain and lightweighting.
- **Mega Data sharing**: Driving pattern information in Mega cities and worldwide EV data book. Utility Factors for PEVs.
- **Roadmap and Strategy**: Identify optimal fuel mix strategies & constraints; recommendations for accelerating EV deployment.







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Highlight of Achievements Since July 2014

- Initiated research on solid electrolyte prototype and testing
- Battery safety study based on shared test data
- New synthesis process for thermal electric materials
- Optimal control and energy management for PHEV
- Charging mode control and impact on electric grid
- Developed an efficient and exhaustive design process for power split hybrid vehicles—close collaboration with Ford and DENSO
- Wireless Charging demo with DENSO
- Initiated modeling effort of connected and automated vehicle technologies
- Life Cycle Analysis of Buses

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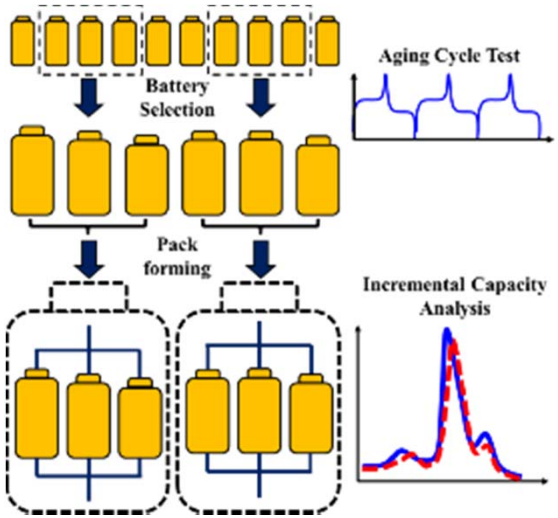
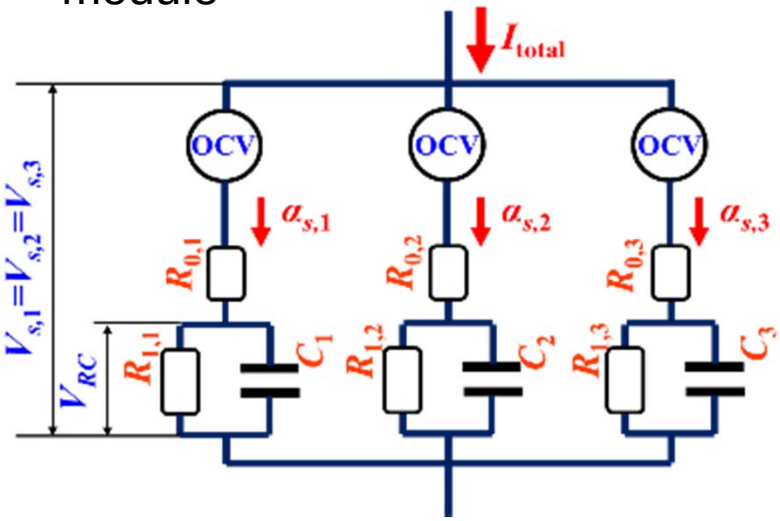
Battery safety study based on shared test data

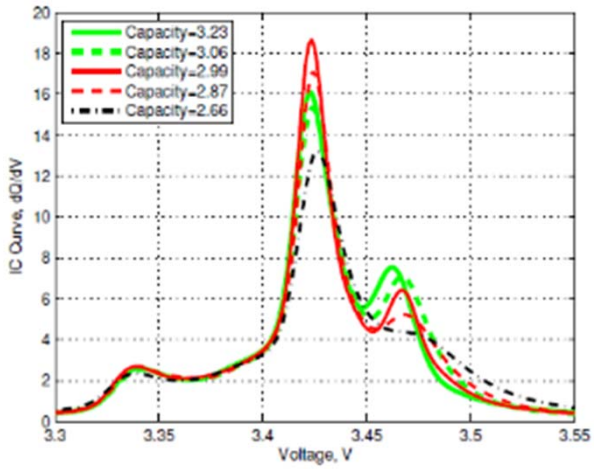
- Module formation for capacity degradation test

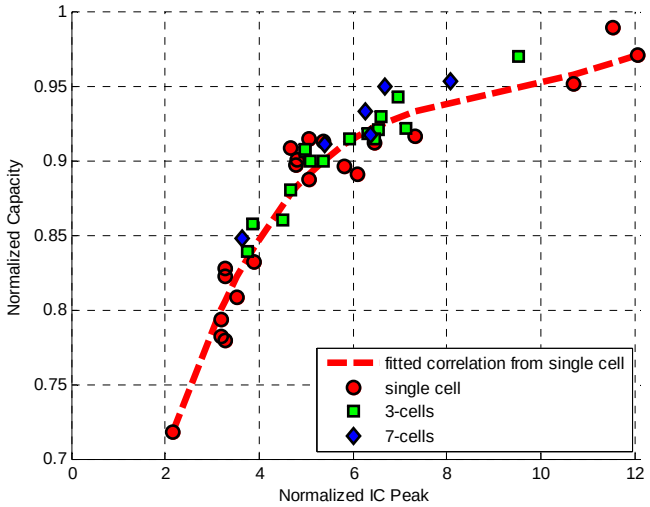


- Module model for Li-ion battery module



- ICA for module capacity degradation diagnosis





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New synthesis process for thermal electric materials

- Apply Self-Propagating High Temperature Synthesis (SHS) to thermoelectric materials, with a focus on skutterudites, Mg_2Si, half-Heusler alloys and Bi_2Te_3.
- Study uniformity of SHS-synthesized materials using Scanning Thermoelectric Microscopy (SThEM).
- Construct and test the performance of a prototype thermoelectric module.
- Seek industrial partners for large scale module development based on SHS fabricated thermoelectrics.

SHS for skutterudites

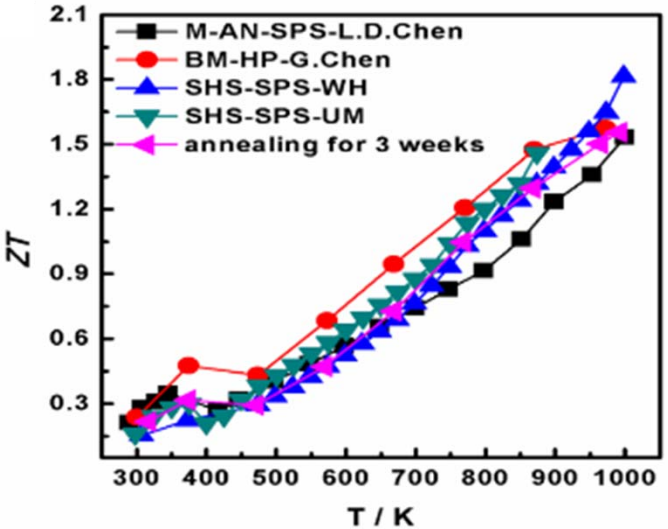
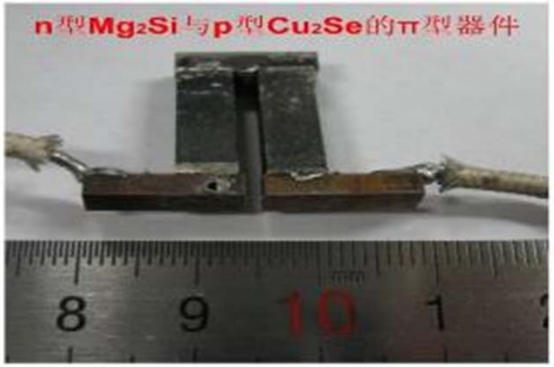


Figure of merit of SHS-synthesized Cu_2Se [*Nature Commun.*]



A thermoelectric couple developed jointly by UM and WHUT using n-type Mg_2Si and p-type Cu_2Se with conversion efficiency of 7%

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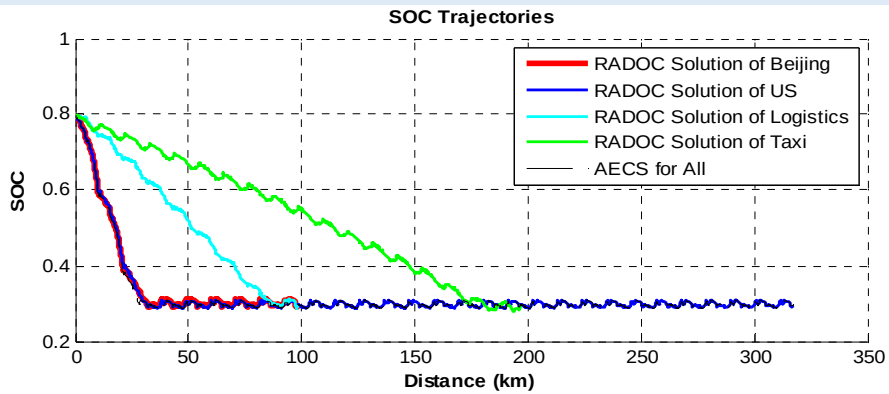
Optimal Control and Energy Management for PHEV

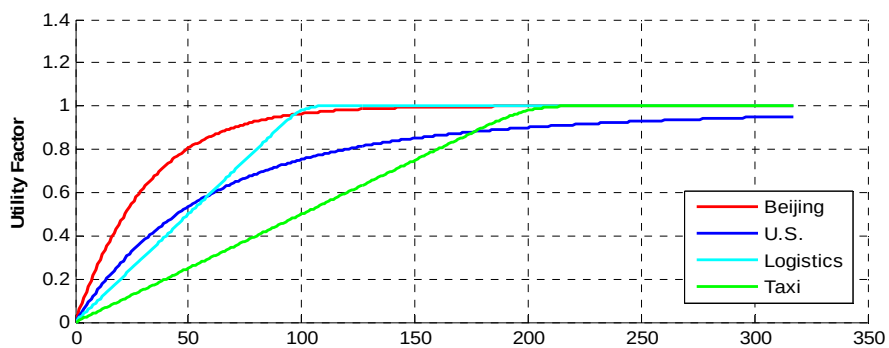
1. Conventional all-electric-charge-sustaining (AECS) strategies are good for maximum battery use;
2. Blended Strategies are beneficial for the fuel consumption of long-range travels;
3. PHEV optimal energy management strategies should be adaptive to the different daily travel distances, and the average fuel consumption should be the optimal target.

Research Outcomes:

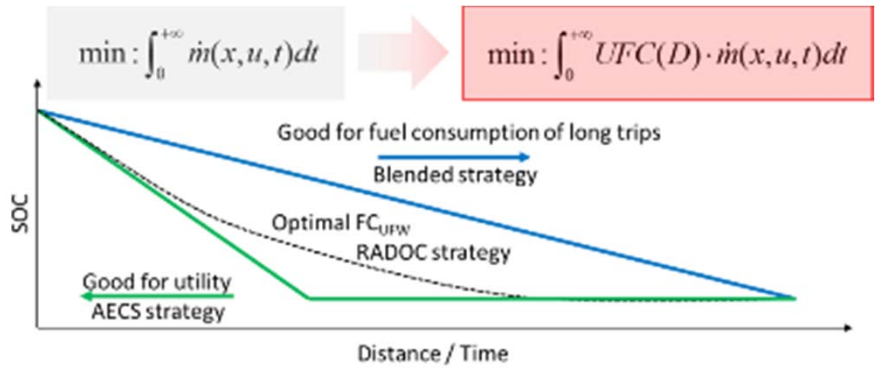
The Range Adaptive Optimal Control (RADOC) algorithm achieves balance between maximum electricity use (AECS) and high fuel economy. The utility factor is used to represent average trip length distribution. We studied the benefit for US and China trips.



SOC track of optimal strategies for different range distribution



UF curves for different range distribution



Range Distribution	Beijing	US	City-Delivery Cars	Taxi
AECS (L/100km)	2.24	3.37	3.74	4.41
RADOC (L/100km)	2.22	3.35	3.59	4.33
FC decrease percentage	0.72%	0.69%	4.07%	1.82%

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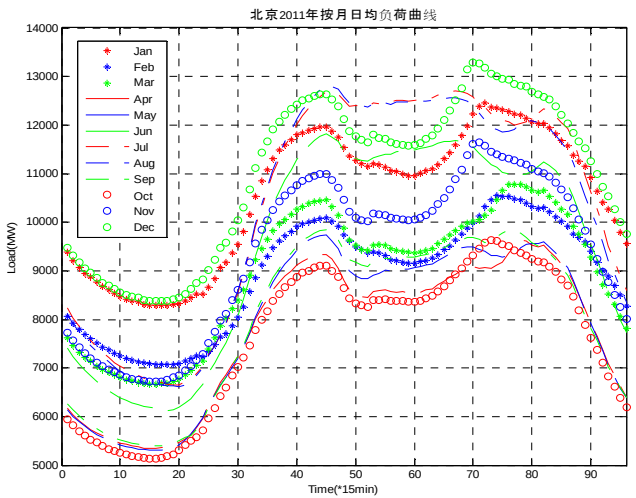
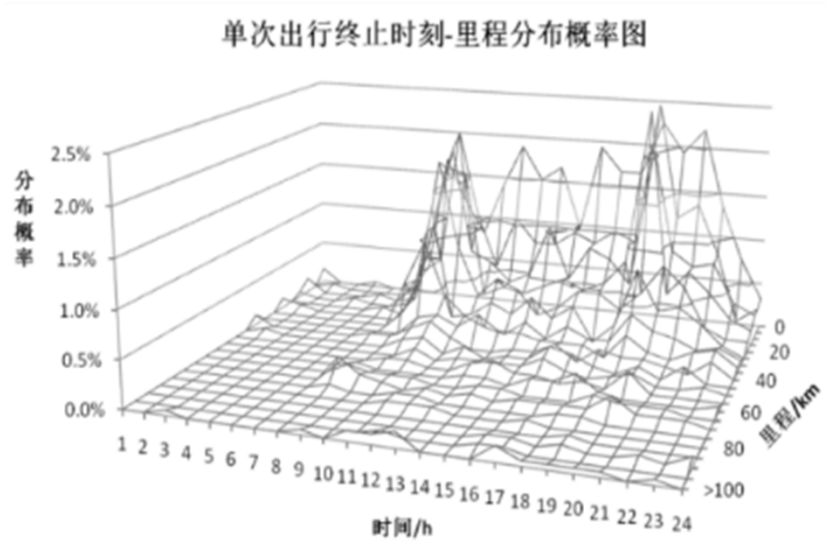
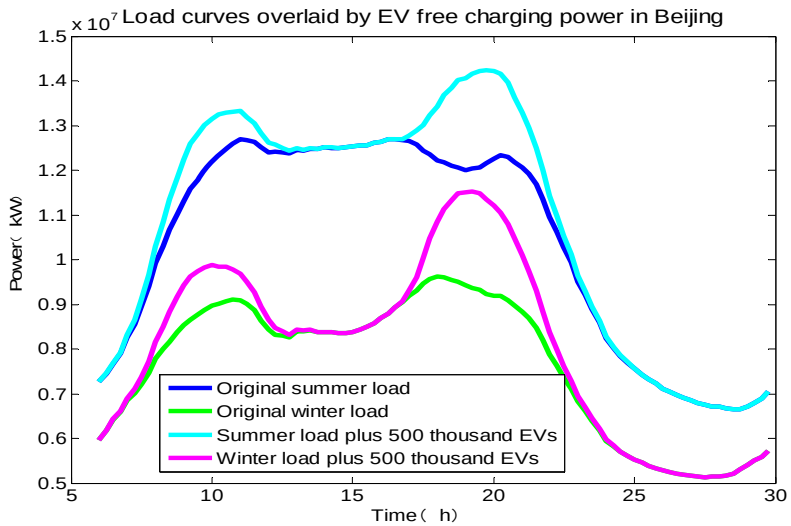
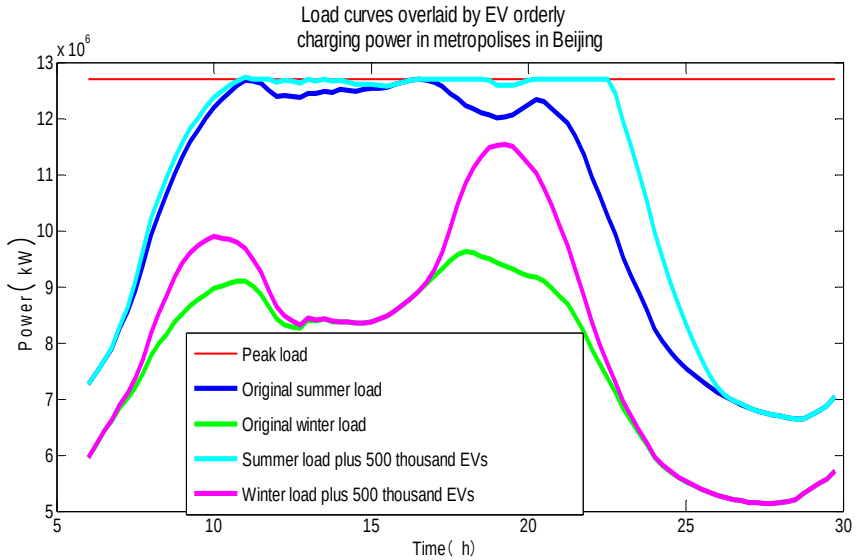
Charging mode and impact on electric grid





Electricity load curves in Beijing （2011）





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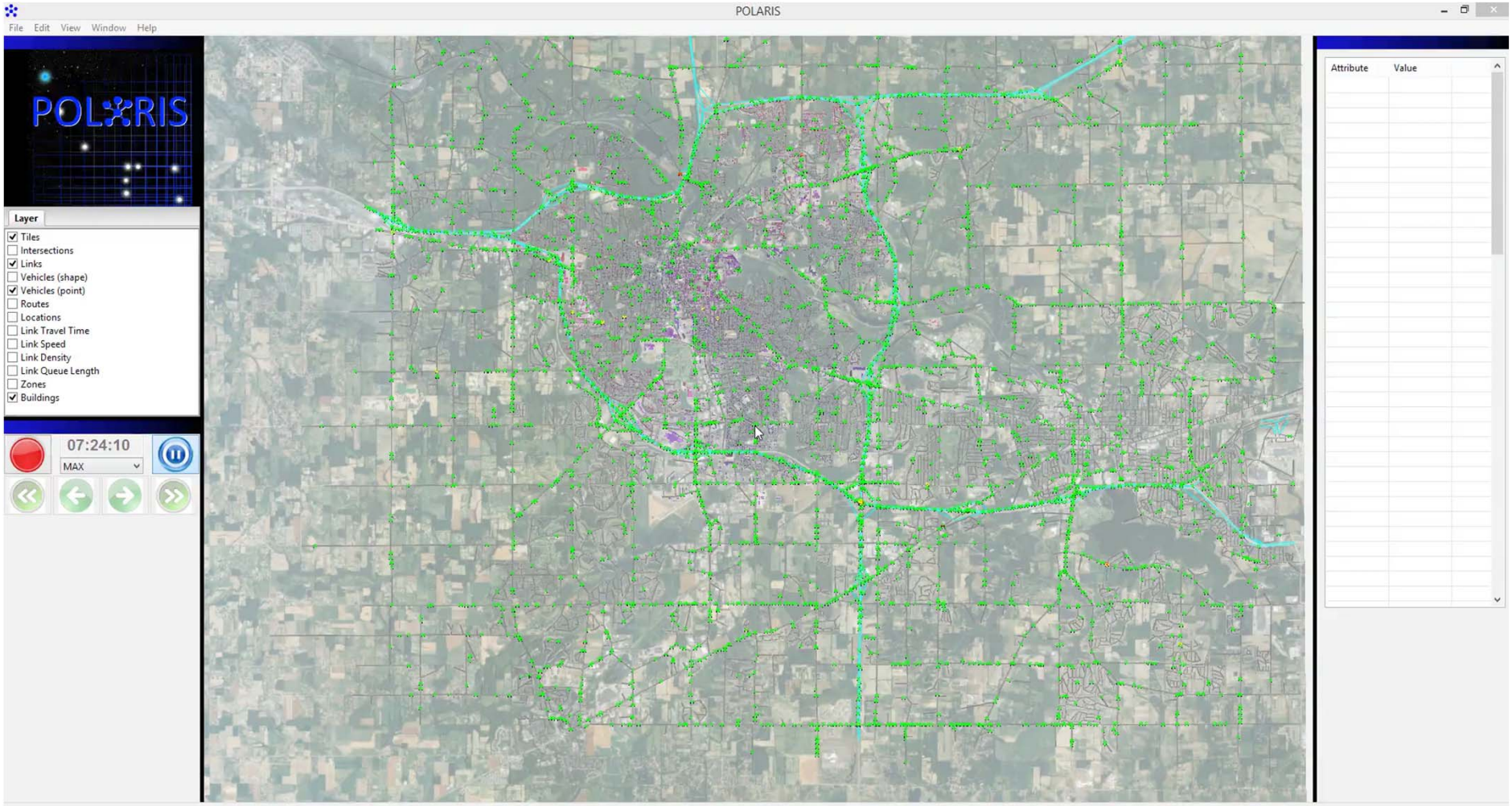
Modeling of Connected and Automated Vehicle Technologies

(collaboration between UM and Argonne National Lab)



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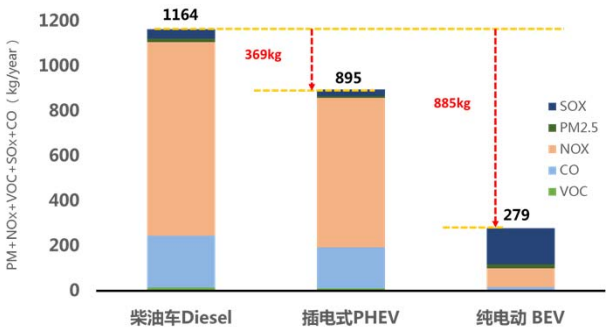
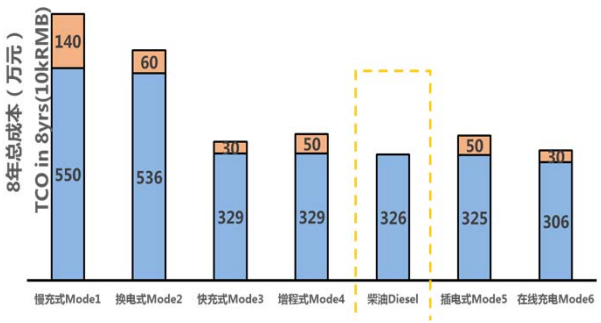
Life Cycle Analysis of Buses

LCA of 6 electrification technologies/business-modes for city Buses (China)

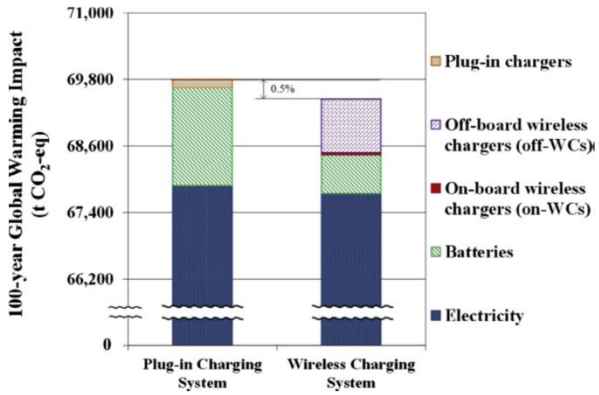


The NEV buses has significant environment benefits in reduced CO2, PM2.5 and NOx

The Fast charging and Online charging modes have significant benefit in TCO

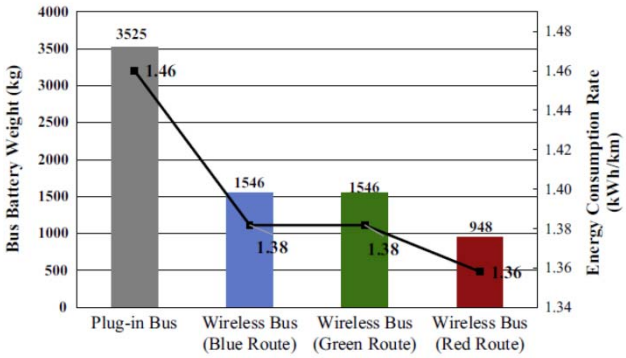


LCA of Plug-in and Wireless Charging for Electric Buses (Ann Arbor)



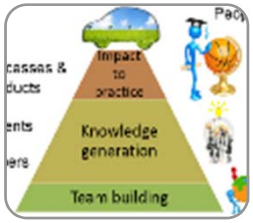
Wireless charging system vs plug-in charged system @ transit bus @ US grid

- Battery size downsized to 27–44%
- 0.3% less energy
- 0.5% less life cycle GHG

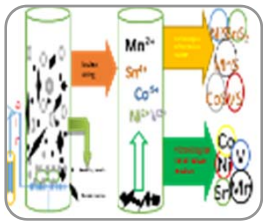


Outline

Summary of CERC 1.0



Final Year of CERC 1.0



Plan for CERC 2.0

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Pathways to Implementation Projects

UM-Siegel	Demonstration of Solid-State Batteries
UM-Peng	A Systematic Design Procedure for Double Planetary Hybrid Vehicles
OSU-Rizzoni	Torque Security in an Electrified Vehicle
UM-Ni	Friction Stir Welding of Dissimilar Metals
UM-Mi	A Wireless Magnetic-Resonance Power Transmission System for EV Charging
UM-Keoleian	Electricity and material sourcing scenario analyses to guide vehicle technology strategies

Ford: F-150 power split hybrid design

DELPHI: Diagnosis of electrified powertrain

EATON: Drivetrain lightweight structure simulation

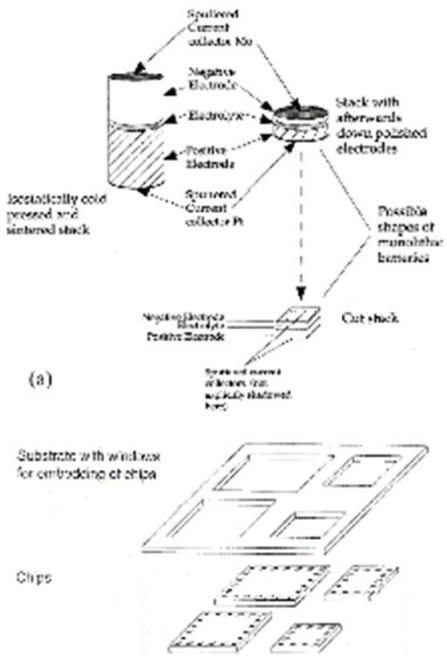
DENSO: Wireless charging prototype

One-year additional funding with clearly defined "tech transfer target"

All projects with identified industrial sponsors

Solid State Batteries

- Higher energy density and potentially lower cost batteries



Weppner *et al.* (1999)

Climate Change Committee (2012) Final Report prepared by Element Energy Limited, Cambridge, UK .

+) No organics to degrade
+) Synthesized and fabricated in air
+) Significant reduction in packaging
+) Non-flammable
+) Gets better with increasing temp

?) Interface integrity
?) Kinetics/Power
?) Thermomechanical stresses

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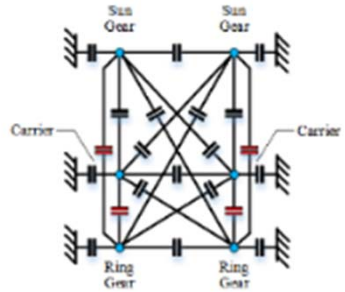
Double Planetary Gear Hybrid Trucks

Automated modeling, mode screening and identification

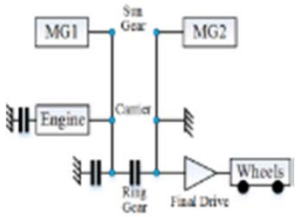
Drivability screening

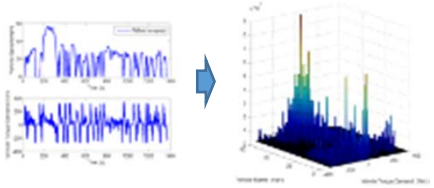
A fast and near-optimal control strategy – the PEARS+

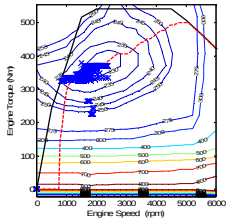
Design candidates in a manageable space

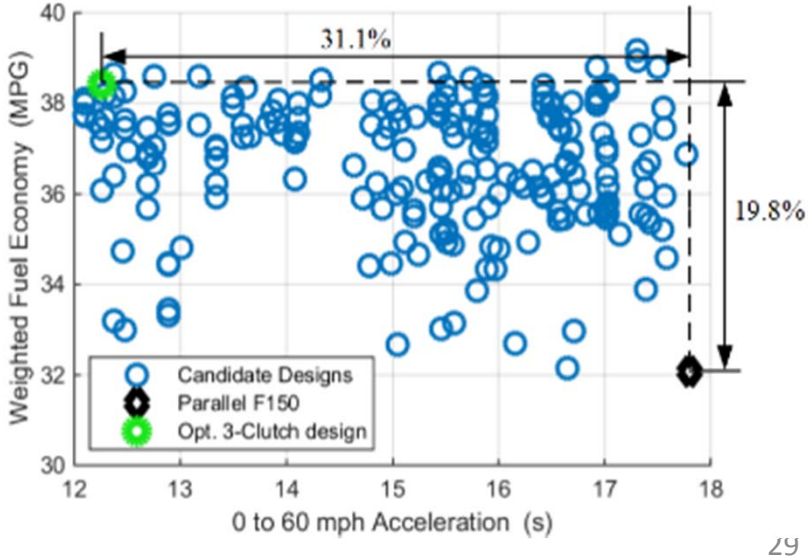


$$\begin{bmatrix} \dot{\omega}_{out} \\ \dot{\omega}_{eng} \\ \dot{\omega}_{mg1} \\ \dot{\omega}_{mg2} \end{bmatrix} = A^* \begin{bmatrix} T_{load} \\ T_{eng} \\ T_{mg1} \\ T_{mg2} \end{bmatrix}$$

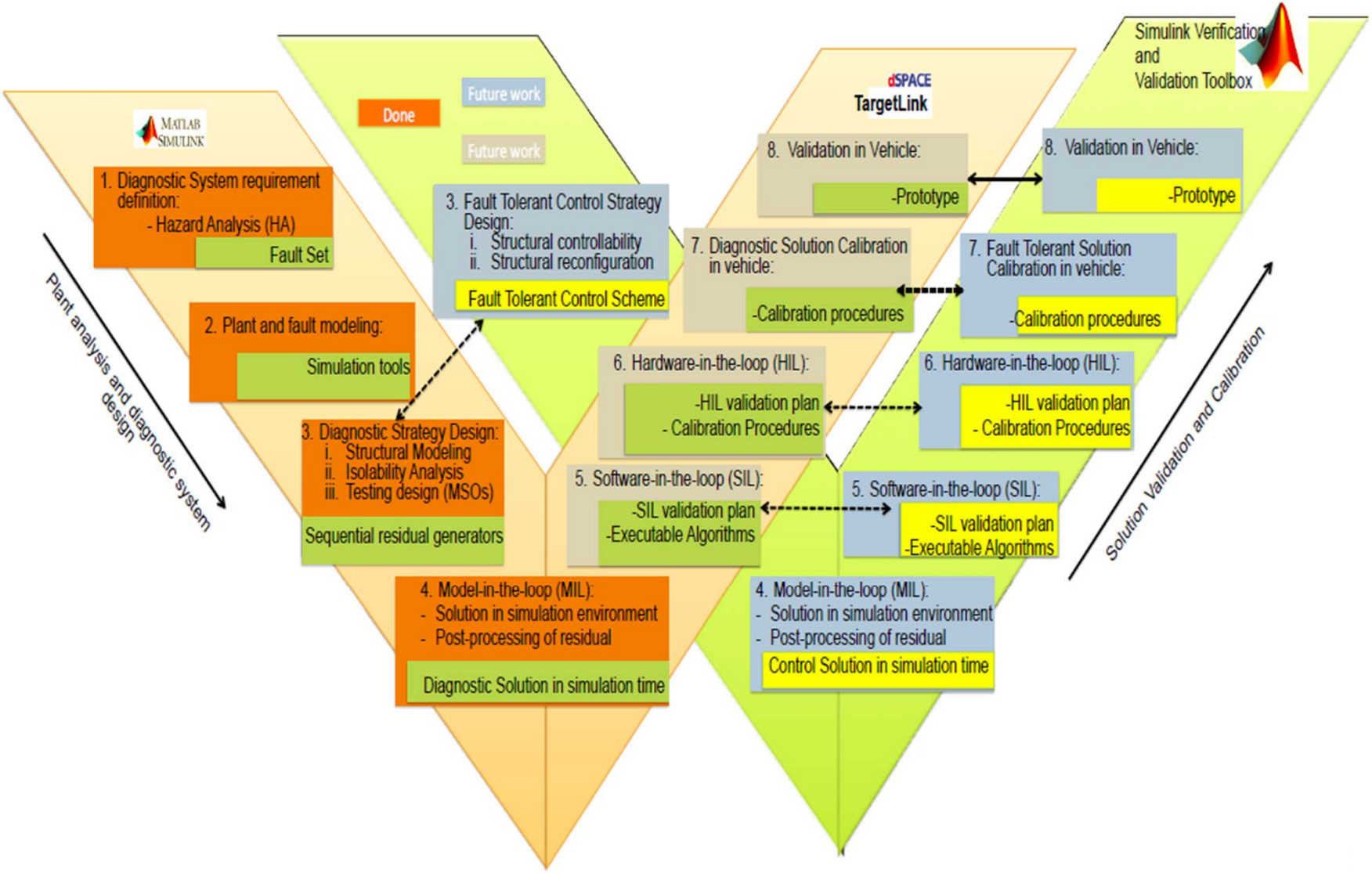






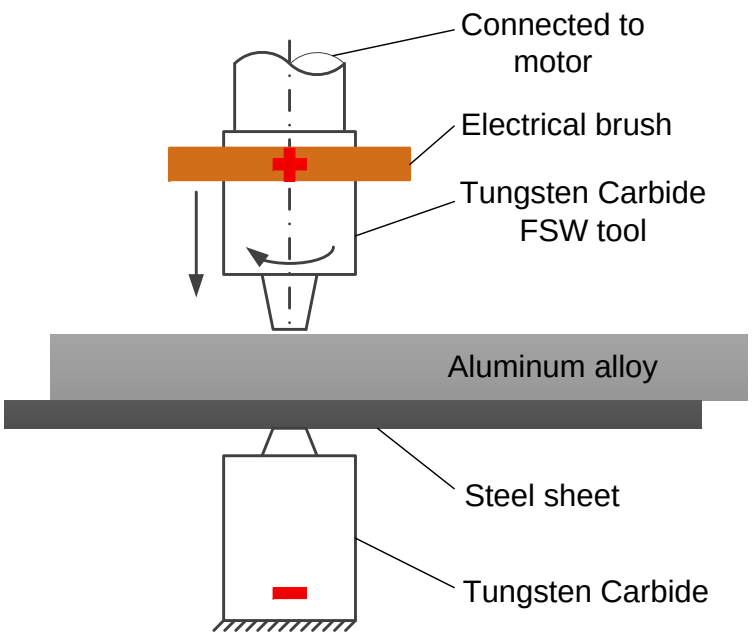


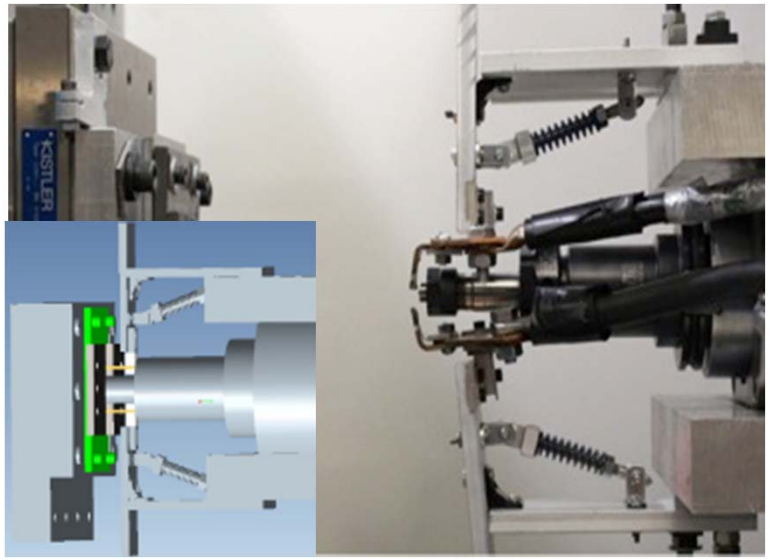
Torque Security of EV

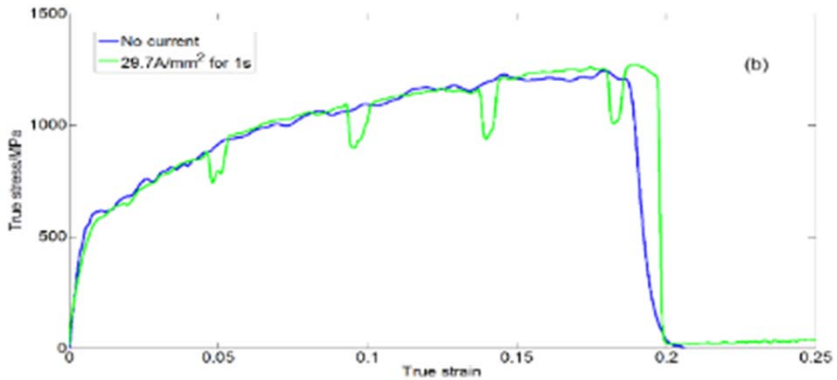


Electrically Assisted Friction Stir Welding

- Extend existing FSW to spot welding and work piece of different materials and thickness.







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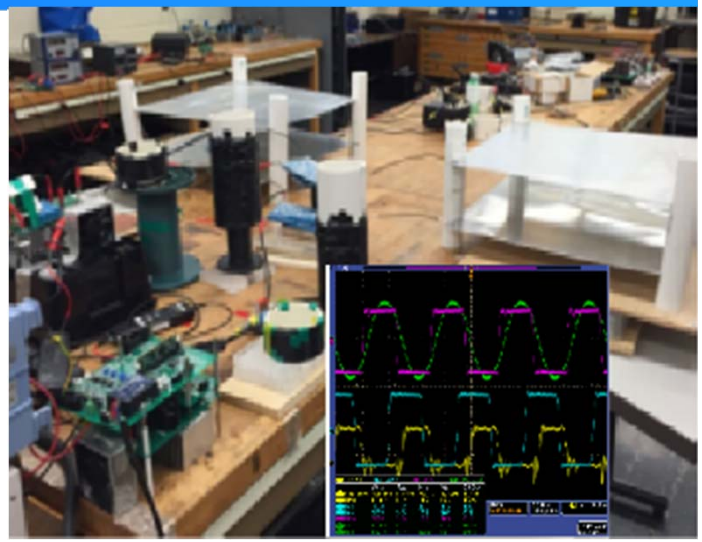
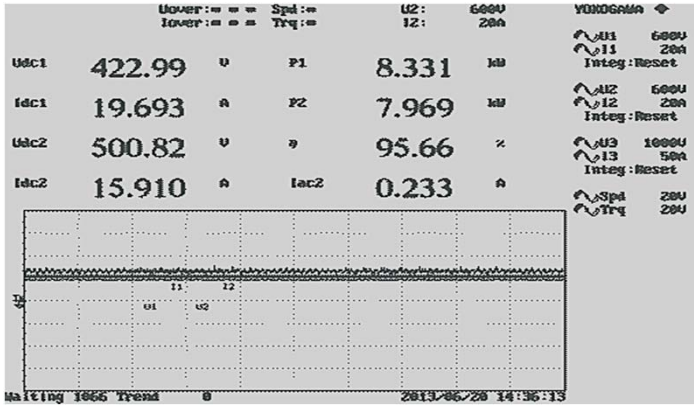
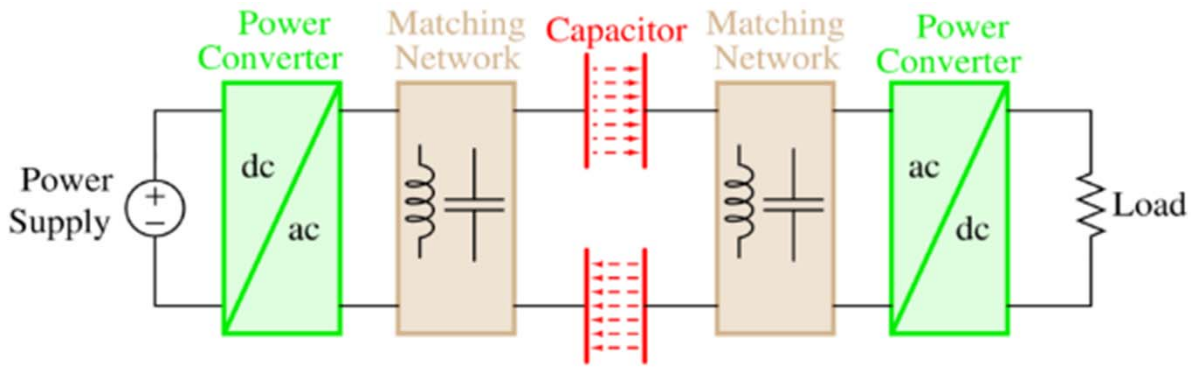
Wireless Power Transmission System for EV Charging

- Work with DENSO to build a 22kW double-sided production-feasible wireless charging system (eff ~ 93%), and to integrate the system into a production-intent EV or HEV.
- Demonstrate/validate functions of WPT and solutions to practical issues (communications, object detection, safety, misalignment, standards).
- Will develop IPs on capacitive power transfer and live object detection





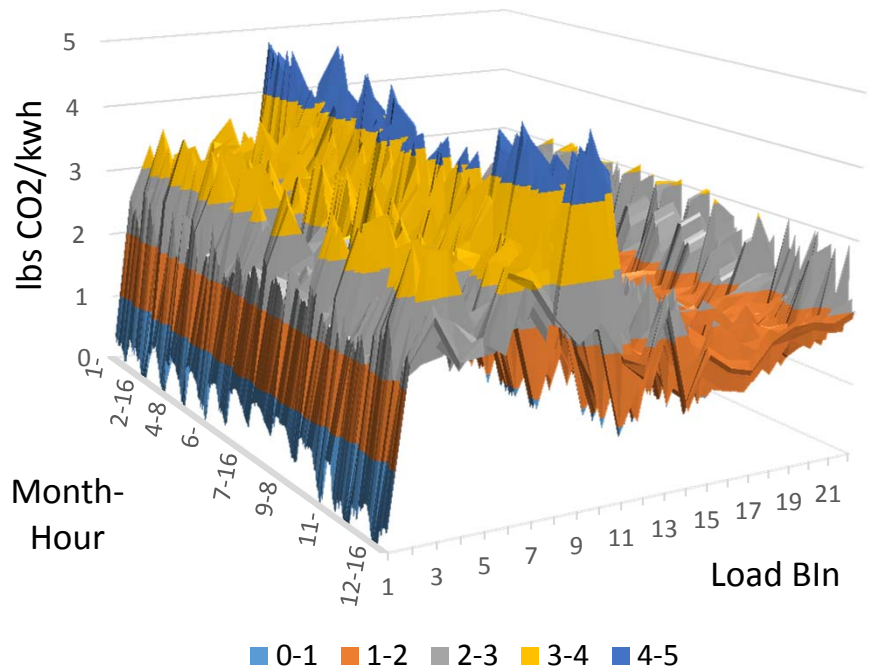


Electricity and Material Sourcing Scenario Analysis

Regional Electricity Grid Emissions Model

- The GHG emissions model will address:
  - Temporal variation
  - Future fuel prices
  - Generator retirements and additions
  - Electricity imports and exports

Grid Emissions Model then can be used to support algorithm for implementation decisions and roadmap



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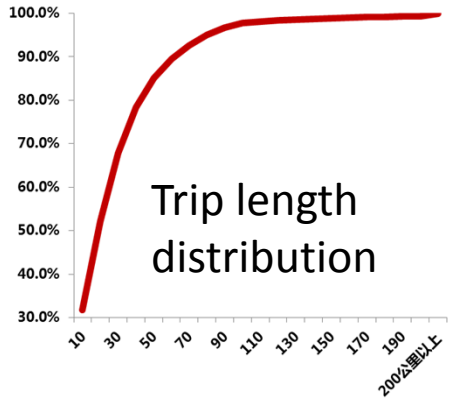
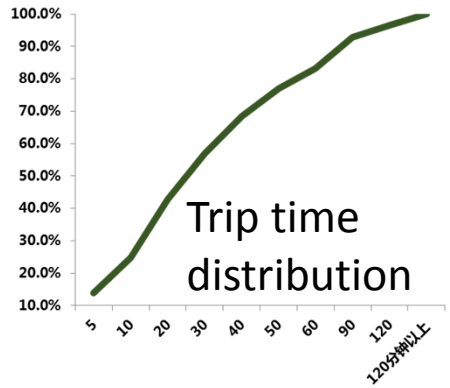
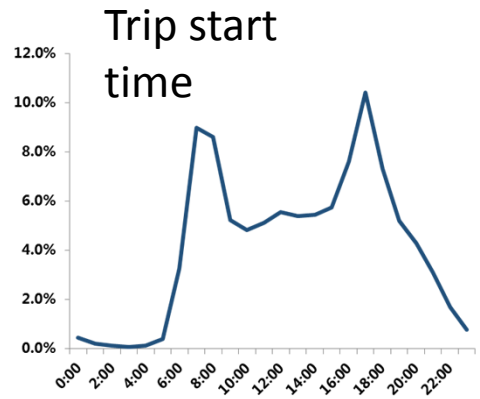
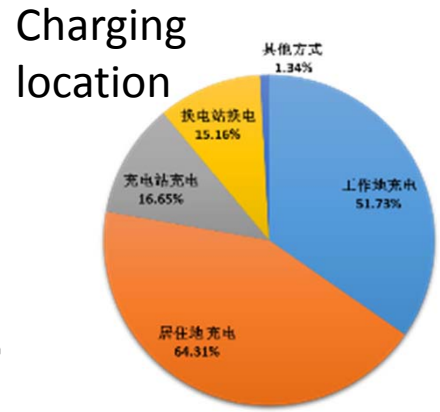
PHEV Driving Behavior in a Mega City (Shanghai, 2014)

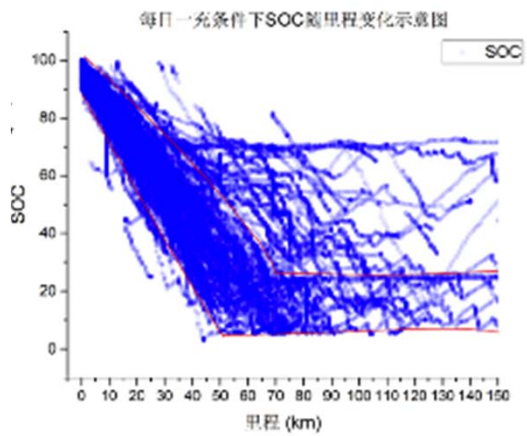






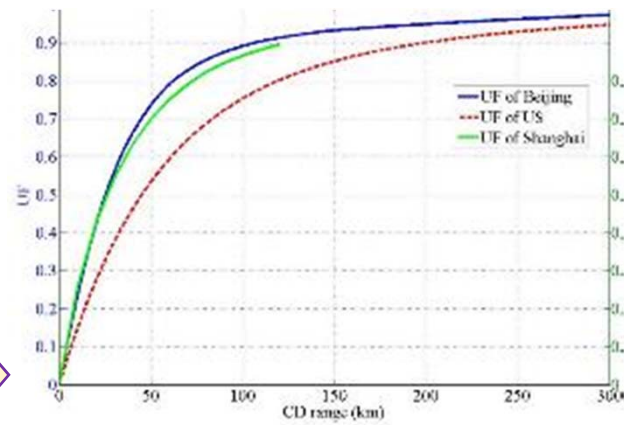


Based on 50 Qin PHEV vehicles (made by BYD) 333,000km, 10,000 trips, 7,500 days, 3,300 charging events



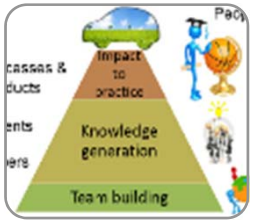
Data based battery performance model

Utility Factor vs. charging & driving behavior

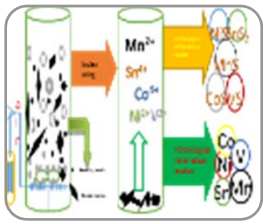


Outline

Summary of CERC 1.0



Final Year of CERC 1.0



Plan for CERC 2.0

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CERC-CVC 2.0: Organization

Argonne NATIONAL LABORATORY

Director:
Don Hillebrand

Deputy Director:
Michael Wang

mqwang@anl.gov

Deputy Director:
Khal Amine

Director:
OUYANG Minggao

Deputy Director:
Wang Hewu

Deputy Director: Qiu Xinping

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CERC 2.0 CVC: Target, Thrust Areas & Milestones 2016-2020

Background

U.S.-China Joint Announcement on Climate Change 2014

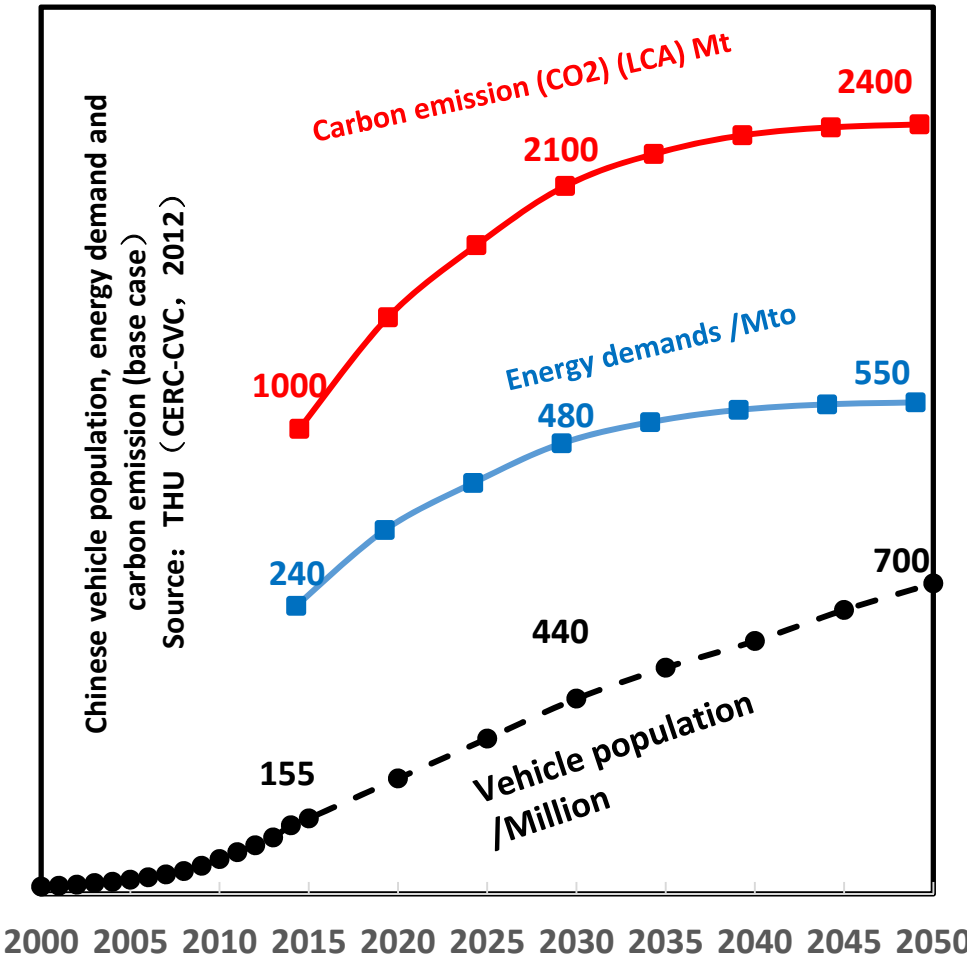
- China intends to achieve the peaking of CO2 emissions around 2030 and to make best efforts to peak early
- The United States intends to achieve an economy-wide target of reducing its emissions by 26%-28% below its 2005 level in 2025

Chinese BAU scenario @ 2030::

- Vehicle population 440million, tripled(2015)
- Transpt. Energy demands 480Mto, doubled
- CO2(LCA) 2.1 Billion tone, doubled

Pathways to limit CO2 emission:

- Electrification (higher efficient)
- Lower carbon power(more renewable)
- Higher CV market share(early penetrated)



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CERC-CVC 2.0: Targets, Contents and Milestones 2016-2020

Thrust areas (from CERC-CVC 1.0 to CERC-CVC 2.0)

CERC-CVC 1.0

Advanced Battery Materials and System Integration

Clean Combustion and APU

Vehicle Electrification Configuration and Optimization

Lightweight Structures

Vehicle-Grid and Infrastructure

System Analysis and Roadmaps

CERC-CVC 2.0

Energy Storage Systems

Advanced Vehicle Technologies

Connected Vehicle and Infrastructure

Systems Analysis and Policy Instruments

CERC-CVC 2.0: Targets, Contents and Milestones 2016-2020

1. Energy Storage Systems

1.1 Advanced Battery Technologies

- Li-S Battery: energy density reach 400wh/kg, battery lifetime 500 cycle
- Solid Battery: energy density reach 300wh/kg, battery lifetime 2000 cycle
- Zn-Ion Battery： Low cost ($0.1/Wh), improved safety, eco-friendly

1.2 Safety and Durability

- Degradation of battery structure under cyclic thermo-mechanical stress
- Multi-level safety mechanism based on materials, interface, cell, module and system
- Initiation and propagation mechanisms of battery thermal runaway

1.3 Battery Management System

- System dynamic modeling
- Modeling-based battery state evaluation methodology
- Battery management systems

CERC-CVC 2.0: Targets, Contents and Milestones 2016-2020

2. Advanced Vehicle Technologies

2.1 Clean Combustion/Alternate Fuels

- Clean combustion technologies
- ICE electrification
- Thermal - mechanical - electric coupling

2.2 Alternate powertrains

- Distributed drive electric vehicle (passenger car)
- High efficient electric motor
- PHEV electric power split systems

2.3 Light Materials and Crash Safety

- Light weight materials
- Structural durability of power batteries
- Crush safety

2.4 Heavy-Duty Vehicle Technologies

- Hybrid vehicle technologies
- Fuel-cell vehicle technologies

CERC-CVC 2.0: Targets, Contents and Milestones 2016-2020

3. Connected Vehicle and Infrastructure

3.1 Connected and Automated Vehicle

- Develop a virtual environment to evaluate the impact of CAVs
- Quantify the energy and mobility impact of CAVs for multiple

3.2 Testing and Evaluation

- Data analysis of field operation test results
- Demonstration projects: Collaborative research on the needs to control automated vehicles, data collection, experimental facilities
- Testing and evaluation of automated vehicles

3.3 Wireless Charging

- Standards, safety and efficiency
- Low cost, high efficiency

3.4 Charging Infrastructure

- Standards and inter-operability
- Integration of power grid and information grid

CERC-CVC 2.0: Targets, Contents and Milestones 2016-2020

4. System Analysis and Policy Instruments

4.1 Technology Impacts Assessment

- Battery performance degradation evaluation using fleet test data
- Travel behavior and optimized energy use
- Vehicle and battery driving cycle

4.2 Lifecycle Analysis

- Energy and emission effects of connected and automated vehicles
- Battery materials, battery packs, battery second use, and recycling/disposal
- Benchmark and Testing

4.3 EV Roadmap

- EV business model development
- Incentive policy research (subsidies, tax exemptions, ZEV requirements, etc.)

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CERC 2.0 CVC: Target, Contents & Milestone 2016-2020

Key Annual Milestone

TA4

- Energy storage and battery second use in smart grids
- NEV fleet travel behavior and optimized energy use
- ZEV credit policy to accelerate NEV market adoption in China

TA3

- Wireless charging eff. >95%， Cost < $50/kw
- Build connected vehicle testing and evaluation platform
- Demonstrate energy saving benefit of connected and automated vehicles>20%

TA2

- High Efficient Electric Motor
- Light Weight Materials
- New Energy Heavy Duty Vehicle Technologies
- Efficiency of hybrid engines > 55%

TA1

- BMS Industrialization
- Zn-Ion Battery Cost: $0.1/wh, 1kw/kg
- Breakthrough in the safety and durability of Li-NMC batteries
- Solid Battery: > 300Wh/kg，2000 lifecycles
- Li-S Battery：>400Wh/kg，500 lifecycles

2016 2017 2018 2019 2020

Thank you for your attention!