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Summary Report on the SAE 2016 Range Extenders for Electric Vehicles Symposium

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March 2017

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OAK RIDGE NATIONAL LABORATORY
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Summary Report on the SAE 2016 Range Extenders for Electric Vehicles Symposium

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ACRONYMS

Al-air	Aluminum-air
APU	auxiliary power unit
BEV	battery EV
EREV	extended range EV
EV	electric vehicle
GHG	greenhouse gas
HD	heavy duty
ICE	internal combustion engine
LD	light duty
MD	medium duty
PHEV	plug-in hybrid EV
REx	range extender
SAE	SAE International

ACKNOWLEDGMENTS

The authors gratefully acknowledge the speakers and participants from the SAE 2016 Range Extenders for Electric Vehicles Symposium for the ideas presented here. A special thank you to Hugh Blaxill from MAHLE Powertrain Ltd. for co-organizing and Colette Wright and Kimberly Inniger from SAE International for helping to plan and host the symposium. The authors would also like to thank VJ Ewing and Paul Chambon from Oak Ridge National Laboratory for reviewing and editing this report.

EXECUTIVE SUMMARY

The SAE 2016 Range Extenders for Electric Vehicles Symposium was a 2-day technical meeting focused on the role of advanced internal combustion engines (ICEs) and other novel energy converter technologies for extending the range of electric vehicles (EVs). The first-of-its-kind symposium was notable for focusing solely on the range extender (REx) technologies and not the EVs. The technical program featured presentations from international leaders from industry, government, national laboratories, and academia. The opening keynote presentations covered a broad range of topics including consumer behavior, policy implications, regulatory considerations, and REx architectures as enablers for advanced technologies. The technical sessions focused on an array of REx technologies including conventional ICEs, as well as less conventional or emerging technologies such as microturbines, fuel cells, low-temperature combustion engines, and aluminum-air batteries. The symposium included two panel sessions.

The trend toward increasing vehicle electrification and the changing role of ICEs and other auxiliary power unit technologies for use as REx's is leading to new research and design development needs. The symposium captured the interest of the industry and research communities in exploring the opportunities and challenges associated with REx's for EVs. This report includes key takeaways, summarized below, and draft notes for each presentation and panel discussion.

Key Takeaways

- About 50 representatives of industry, government, research laboratories, and academia attended the symposium. This was higher than expected for a first-time SAE International (SAE) symposium and included attendees from U.S. and international automotive OEMs and suppliers spanning the light, medium, and heavy duty vehicle segments.
- Overall feedback from speakers and attendees was that the symposium was timely and in line with ongoing strategy development.
- Several keynote presentations included reference to the potential synergies of REx's and biofuels for deep decarbonization in future fleets (2050 goals of 80% decarbonization).
- Presentations spanned conventional ICEs, REx purpose-built ICEs, microturbines, fuel cells, and novel battery technologies and included detailed technical presentations and discussions on purpose-built ICEs versus the use of existing engine technologies for REx applications.
- Panel discussions and some presentations mentioned the role of REx technologies in emerging transportation paradigms such as shared vehicle economies, autonomous and connected vehicles, etc.
- Two broad REx technology pathways became apparent from the presentations:
  (1) REx technologies to extend the range of EVs and
  (2) the use of electrification to enable technologies that are currently impractical or difficult to use as prime movers (e.g., microturbines, low temperature combustion engines).
- Discussions went well beyond vehicle fuel economy to include cost; weight; noise, vibration, and harshness; emissions; and fuel opportunities. As an example, the microturbine applications are more concerned with low emissions than high efficiency. These trade-offs dominated much of the question and answer sessions.

At the time this report was written, SAE had approved holding a second REx symposium in 2017. Updates on status can be found at SAE events (http://www.sae.org/events/) or by contacting the organizers (see Sect. 4).

1. INTRODUCTION

The SAE 2016 Range Extenders for Electric Vehicles Symposium was held November 2–3 in Knoxville, Tennessee. The organizers for this first-of- a-kind symposium focusing on current and future range extenders (REx's) were Scott Curran from Oak Ridge National Laboratory, Robert Wagner from Oak Ridge National Laboratory, and Hugh Blaxill from MAHLE Powertrain Ltd. The 2-day meeting focused on the role of advanced internal combustion engines (ICEs) and other novel energy convertor technologies in extending the range of electric vehicles (EVs). This symposium differed from other conferences on hybrid and EVs, which typically focus on the vehicle system or electric powertrain, by focusing solely on REx technologies. There were about 50 attendees, which was higher than expected for a first-time SAE International (SAE) symposium and included attendees from U.S. and international automotive OEMs and suppliers, spanning the light, medium, and heavy duty (LD, MD, and HD) vehicle segments. The technical program [1] featured talks by international leaders from industry, government, national laboratories, and academia. The opening keynote presentations covered a broad range of topics, including consumer behavior, policy implications, regulatory considerations, and REx architectures as enablers for advanced technologies. The technical sessions explored REx technologies, including conventional ICEs and less conventional or emerging technologies such as microturbines, fuel cells, low-temperature combustion engines, and aluminum-air batteries. The symposium also included two panel sessions.

Section 2 provides a summary of the key points from the symposium and from the panel discussions. A list of all the presentation titles, as well as abstracts from the presentations, can be found in the online program (http://www.sae.org/events/pdf/rex/2016_rex_guide.pdf). Appendix A reproduces a summary article on the 2016 REx symposium from Green Car Congress [2].

2. SYMPOSIUM OVERVIEW AND KEY POINTS

The 2016 SAE REx symposium was organized around three central themes.

- Broader challenges and opportunities for REx technologies and EVs
- Emerging REx technologies
- Long-term opportunities and challenges of REx technologies

The following sections summarize the key points from those themes.

2.1 BROADER CHALLENGES AND OPPORTUNITIES FOR REx TECHNOLOGIES AND ELECTRIC VEHICLES

Transportation accounts for more than 30% of US energy consumption and recently became the highest sector for greenhouse gas (GHG) emissions. The increasingly difficult to meet fuel economy standards, criteria air pollutant standards, and tailpipe GHG emissions targets are driving the automotive industry toward electrified powertrains. The range of powertrain electrification options, starts with micro hybrids, which retain a full-size engine but allow for start-stop operation, and then moves to full hybrids such as the Toyota Prius, followed by plug-in hybrids, which act more like an EV but still use a blended power strategy, and finally a REx hybrid. The auxiliary power units (APUs) used as REx's are completely decoupled from the vehicle tractive power and speed demands except for an electric power coupling.

Annual sales for plug-in hybrid EVs (PHEVs), including extended range EVs (EREVs), remain small, but the market has seen a significant increase in the number of PHEV models for sale in the United States in 2016. The number of models is up across most LD segments (e.g., two- seaters, small to large sedans, luxury cars, sports cars) except for LD trucks. The complexity of these powertrain options and the interdpendance of components will have signficant impact on potential solution space over this range of electrification. How do we get to 80% decarbonization by 2050, and what are the pathways? A sense of urgency is needed to meet 2050 goals because by 2035, automakers need to be selling vehicles. This means they need to be developing the vehicles by 2030. This challenge poses a big question: What is the role of electrification in meeting these goals? Looking at different scenarios, what combinations look interesting? Ultimately what may be most compelling are mixes of technologies. We expect to see heavily downsized boosted engines, strong hybridization, compression ignition engines, mixes of downsized boosted with hybridization, EVs . . . . In this context, a compelling argument can be made for REx's; however, it will require a combination of market, technology, and industry knowledge to properly evaluate all options.

The following are some of the key points made and questions raised regarding broader challenges.

- What solution could work way out there on the time line (i.e., 2050)? Biofuels with EREV could be a valuable combination. When you want to travel between cities you can't compete with the energy density of liquid fuels; batteries can't do that in the near term. Emissions between cities are relatively low with high-efficiency engines; if you can achieve a net zero CO_2 fuel, maybe the sweet spot is 60 miles of electric range.

- EV development is shaped by multiple factors. We want EVs that customers not only choose to purchase but love to own (not just accept). There needs to be emotional appeal to the vehicle, otherwise we won't sell any. These attributes must go in the mix, incorporate the whole value chain while being conscious that it is more than just technology that drives a purchase; it must also be compelling.

- How do we enable high-volume electrified vehicles, reduce cost (it is that simple)? We are currently in the range to reach $150/kWh; however, if we are going to get to high volume, we need to get below $100/kWh. Is this evolutionary or revolutionary?

- All markets have the same challenges, and CO_2 regulations are all headed in the same direction. A practical approach is needed; different vehicles require different amounts of energy, and different propulsion systems have different efficiencies of converting stored energy.

- The range of current battery EVs (BEVs) is remarkable. Current battery technology has enabled the modern long-range BEV. The high overall powertrain efficiency of BEVs is the cause for energy consumption sensitivity. Recharging rates at Level 1 or Level 2 result in 5–12 miles per hour of charge; Level 3 charging results in 165 miles per hour of charge. It's worth noting that for gasoline the driver gets ~10,000 miles per hour of "charging" (fill-up).

There was an extended moderated question and answer session with each of the first four speakers to allow for discussion among the speakers and interactions with symposium attendees. Some of the more interesting points are summarized below.

- **Question:** Range extenders, are they more about relieving range anxiety or an important part of the technology mix?

  Answers:

  - 90% of the time it is about mitigating range anxiety; 10% of the time there is a real need to actually extend the range past what currently available EVs are capable of for US drivers.

- People go out and buy vehicles to meet all needs. Current EREVs are capable of upwards of 1,000 miles of daily driving between gasoline fill-ups. For the vast majority of driving, most people don't need a REx that often but buy them for the few times a year they really need them.
- A REx offers the reassurance that you won't be stranded. We must also consider that purchase decisions are not necessarily made on objective data, . . . worth noting that only a small fraction of people who buy pickup trucks actually have enough need for the utility to warrant a dedicated pickup.
- If you think about the long term and REx vehicles, this technology can enable a significant change to vehicle emissions. There are a lot of technologies that will lower emissions incrementally, but REx's afford some unique opportunities. For example, with a conventional vehicle you have to use the ICE to go from a cold start; with an EREV you can start on electricity, preheat the catalyst, and reduce emissions significantly.

- **Question:** What happens in the marketplace if you remove all regulations and tax credits? Would a customer pay for an EREV if there were no regulatory benefit or tax benefit? For pure EVs, how many would you sell if there were no market stimulation? (Good open-ended question that warrants a closer look at the data.)

- **Question:** Is industry poised to introduce new levels of electrification to get us to 2025, and will we be ready?

  Answers:

  - Scenarios show that we have the technological capability to get us there, so it comes down to the pathway we choose and the costs we are willing to accept to get there. How do we get to that point, meet customer needs, and optimize for cost?
  - All major OEMs are planning to meet CAFE standards; however, widespread electrification is driven by customer demand, the need to do the best thing for the customer.

2.2 EMERGING RANGE EXTENDER TECHNOLOGIES

One of the primary motivators for holding the 2016 SAE REx symposium was to have a forum to discuss novel technologies suitable for use as REx's in an open technical exchange of information. The trend for powertrain electrification is expected to lead to new opportunities with advanced combustion and next-generation engine development. The ability to partially or completely decouple the engine/APU from vehicle tractive power and speed demands with increasing levels of electrification opens a new solution space to the challenges for implementing next-generation combustion concepts in advanced vehicle powertrains. Promising APU technologies that may not be well suited as the prime movers for a conventional powertrain vehicle could potentially be enabled in a REx application. What is the design space that we can optimize engines around if we can avoid idling and decouple the engine from vehicle speed and tractive power demands? This creates different design requirements for ICEs. The optimal REx technology solution depends on duty cycle.

The following topics were covered in presentations.

- Low-temperature combustion concepts for ICEs
- Specially designed REx ICEs
- Turbines
- Fuel cells
- Aluminum-air (Al-air) batteries

The following were among the key points made about emerging REx technologies.

- Low-temperature combustion (LTC) modes used in a conventional powertrain require full coverage of multimode strategy (where the engine will switch to a conventional combustion mode outside the LTC range), which presents unique challenges. Do you need to do this multimode operation with combustion or can you take advantage of the vehicle electrification to get the equivalent of multimode operation?
- Turbines are an interesting REx technology. They are significantly different in terms of combustion: ICEs have high combustion temperatures resulting in high nitrogen oxide (primarily NO and NO_2) and particulate matter emissions. On the other hand, the turbine is intrinsically very lean, with dilution of gas and a lot of excess oxygen. One of the challenges is in combustor design: to get as lean as you can while avoiding blow-out. By optimizing the design, engineers can get the emissions very low. Even though the efficiency is less than gasoline-powered REx's there are some interesting benefits. Engine life span, good durability; and low noise, vibration, and harshness are all benefits that turbines can have.
- Al-air batteries do not have sufficient power density to be used as propulsion batteries; however, they could be used as extremely energy dense REx's along with power dense Li-ion batteries. This enables shrinking the Li-ion battery, allowing enough range to cover the daily drive and take advantage of regenerative braking, and supplementing it with an Al-air REx to meet needs for longer ranges.

2.3 LONG-TERM OPPORTUNITIES AND CHALLENGES OF REx TECHNOLOGIES

Commercially available range extended EVs are still relatively new to the marketplace. The final theme of the symposium sought to address some of the longer term opportunities and challenges associated with REx technologies. A panel session was organized to lead the discussion of the topic.

The following are some of the key points made about longer term opportunities and challenges.

- Looking beyond 2025 to 2050, will the way we consume transportation change? There could be a broad range of energy impacts if there is another pathway in addition to incremental improvements on today's vehicles. For example, PHEVs being discussed for 2025 look very much like today's vehicles (midsize passenger sedans) and are envisioned as being used in nearly the same way as today. What if in the future there are more specialized cars and new behaviors for shopping (e.g., more online ordering)? Big changes in how we consume transportation may be our most likely pathway to deep decarbonization.

- We need a variety of solutions to meet these aggressive goals of increased fuel economy, reduced emissions and decarbonization. If PHEVs are going to play a big role, what will be the fuel source? For PHEVs to reach the 2050 goals we need scalable low- carbon fuels in addition to electrified powertrains.

- REx configurations have the bonus of generating electricity on board. Having a vehicle with onboard electric generation opens opportunities for providing energy to a house. Future research into investigating REx's for these scenarios could be interesting. A given technology may not make sense just as EREV, but if you look at powering infrastructure, maybe a Stirling heat engine may be more interesting, . . . fuel cells, advanced combustion engines, etc. could also be considered.

- What is the optimal design space for a PHEV? With a blended PHEV, at some point you are going to have an engine start event and associated emissions. If you look at EREVs and BEVs, you have full performance available in electric only mode. The EV operation envelope defines the petroleum displacement potential of a blended PHEV; most can do the urban drive cycle without engine start but the US06 (high acceleration aggressive drive cycle) is a different story. All of these PHEVs require an engine start. EREVs can accomplish the USO6 with 100% CO_2 displacement at 72°F.

- A PHEV REx will be a robust solution in certain markets. Building the right charging infrastructure will be important in further reducing fuel consumption. Smart Cities challenge will provide further insight into benefits of PHEV REx's in support of municipal and commercial goals.

- There is a gap between reality and expectations for the EV at this time: short cruising range, long recharging time; a lot of things we can work on.

- A PHEV solution can be robust like conventional powertrains. Extended range with engine and fast charging could be a viable option for goals in MD segment. This could allow full route coverage with current utilization levels while maintaining payload and working toward the goal of reduced fuel consumption.

2.4 PANEL DISCUSSION

The following are some of the notable questions and answers from the panel discussion.

- **Question:** ICEs are well established; how far behind are other technologies in the REx space?

  Answers:

  - The infrastructure for ICEs is in place. We have seen that there are more efficient technologies that could be used (e.g., the reciprocating engine). The gas turbine is also interesting as it is leveraging established technology for specific applications.
  - For fuel cells, the [projected] rate of adoption is low out to 2030; certainly we will look to see if that is a consensus. On the short-term horizon Li-ion battery technology is showing positive results; battery costs are trending down over time.
  - Reciprocating [engines] is where it is in the near term based on what vocation the idea of turbine or rotary are viable, Al-air makes you sit back and think a little.

- **Question:** Transportation emissions have surpassed electricity generation emissions. The point that is not mentioned is that most of those emissions are from the freight sector. What about REx technology for MD/HD? Is it the same as what we have discussed or is there a new field of emphasis that we should pursue?

  Answers:

  - There is an awareness that LD vehicles have been on a diet for decades. There are 240 million LD vehicles, using 60% of the oil. There is a smaller number of MD/HD vehicles, but they are responsible for more than 20% of the oil used. Need to consider how more zero emission technologies can be brought into the ports. What do we do to take the carbon out of moving freight. The US Environmental Protection Agency is looking at MD/HD regulations as well.

- **Question:** Is there something more revolutionary out there; things discussed were evolutionary not revolutionary?

  Answers:

  - Whatever that engine technology is, it should be robust [as it must contend with the] uncertainty of charging stations, plus it is unclear how hard this engine must work. [We're] looking for the Swiss army knife of solutions; need to make sure that packaging and fit works for the given application.
  - Are we moving toward a shared economy? If vehicles are shared, we will see a tremendous increase in uptime (from 3–4% to over 50%), and we will see the technological approach change and the infrastructure change.

3. SUMMARY

The 2016 SAE Range Extenders for Electric Vehicles Symposium provided a technical forum for leaders from industry, government, national laboratories, and academia to openly discuss the opportunities and challenges for REx technologies to meet consumer needs and regulatory demands. The event captured the interest of international researchers and industry experts, who came to explore the new REx technologies and their potential. The ability to decouple the REx from vehicle speed and load demands to work together with energy storage systems offers new opportunities for vehicle system optimization. The unintended consequences of these systems still has untapped potential and is being explored in new and exciting ways.

4. CONTACT INFORMATION

Questions or comments should be directed to:

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5. REFERENCES

[1] 2016 SAE Rex Symposium Guide, SAE International, http://www.sae.org/events/pdf/rex/2016_rex_guide.pdf.

[2] "SAE REX: PHEVs and REEVs could open door for advanced combustion regime engines" Green Car Congress, Nov 7, 2016, http://www.greencarcongress.com/2016/11/2016.html.

APPENDIX A.

Green Car Congress Summary Article http://www.greencarcongress.com/2016/11/2016.html
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Green Car Congress

Energy, technologies, issues and policies for sustainable mobility

SAE REX: PHEVs and REEVs could open door for advanced combustion regime engines

7 November 2016

Increased market penetration of plug-in hybrid electric vehicles (PHEVs) and range-extended electric vehicles (REEVs) across vehicle segments could present an opportunity for emerging advanced combustion regime engines, such as those using various low-temperature combustion modes, according to a number of presentations at the SAE 2016 Range Extenders for Electric Vehicles Symposium held last week in Knoxville.

The REEV or PHEV also may present opportunities for more novel power sources such as turbines (Wrightspeed), fuel cell stacks (Nissan) or aluminum-air batteries (Phinergy and Arconic), speakers suggested. The REX symposium was sponsored by Mahle; the organizers were from Oak Ridge National Laboratory and Mahle.

In his introductory keynote, Michael Berube, Vehicle Technologies Office Director, Office of Energy Efficiency and Renewable Energy, noted the importance of both engine and fuel technology in a PHEV scenario.

> *If PHEVs are going to play a big role, what is the fuel source for that? How efficient will it be? You're going to need to have very scalable low-carbon fuels if you are going to have PHEVs be a path for deep decarbonization. We certainly believe at DOE that that is a possible path. We don't have one solution that we are here to say is the right one, but we believe that PHEVs could potentially be a key pathway. But to do that, we need to think about the engine.*
>
> *High efficiency engines with low-carbon fuels clearly is a major, major pathway. Not the only one. But we believe this a major pathway.*
>
> —Michael Berube

Berube went on to reference the importance of DOE's major new Co-Optima initiative (earlier post), an effort to co-optimize new fuels and light-, medium- and heavy-duty engines which together could achieve very significant performance improvements. Specifically, Co-Optima is targeting a reduction in per-vehicle petroleum consumption by 30% vs. the 2030 base case, which is constrained to using today's fuels.

In its short life-time, Co-Optima has grown to a 9-laboratory team with more than 130 researchers tackling different aspects of the problem.

> *We believe that [Co-Optima] is a major, major aspect of how we can achieve these [decarbonization] numbers. We believe that, using both of those together, co-optimizing the fuel and the engine, and combining it now with the overall electrified vehicle, you can get dramatic reductions in the overal CO_2 level.*
>
> *The focus is what fuel properties maximize engine perfromance. What if that ICE is now operating in a very narrow range, powering the electric vehicle?*
>
> *What I suggest for you, as you think about PHEVs, think about now having very optimized engines, very optimized fuels that have a high level of renewables in those fuels. You now have a low-carbon fuel that can be operated in engines that are operating in a much more narrow band. Within that*

band, we can get to a very high level of efficiency. There is a very strong case to be made for that PHEV world.

—Michael Berube

In a subsequent talk, Scott Curran from ORNL—one of the organizers of the symposium along with Robert Wagner from ORNL and Hugh Blaxill from Mahle Powertrain—noted that the ability to decouple the engine from the drive cycle, as well as the availability of high voltage current, can help overcome challenges facing advanced engine and emission control systems developers.

The role of the internal combustion engine is changing. We still see a prominent role for these engines moving forward. The ability to refuel large amounts of energy very quickly is going to remain extremely attractive to consumers.

The EPA Tier 3 emissions standards are going to be incredibly difficult to meet. We are going to keep relying on advanced engine technologies to meet these regulations, and as we start looking for higher and higher degrees of electrification, these hybrid systems are going to have to integrate all the opportunities and challenges for the engine, the aftertreatment and the power electronics all to work as one. That's where things start to get really exciting.

As we look along the spectrum of increasingly electrified vehicles, what is the design space that this increasing amount of electrification opens up to optimizing? As we start to explore this higher degree of electrification, there are going to be some very different design requirements for internal combustion engines.

—Scott Curran

One example of the potential for low-temperature combustion (LTC) engine technology for range extended electric vehicles (REEV) presented at the Symposium was work by Ali Solouk and Assistant Professor Mahdi Shahbakhti at Michigan Technological University.

The category of LTC spans a range of specific technologies; these are of great interest as they promise to improve fuel economy, and reduce NO_x and soot emissions by improving the in-cylinder combustion process.

LTC technology faces two main difficulties: first, a narrow operating range, which limits the use of the technology in conventional powertrains; second, complex combustion control, particularly durient transient operations. However, when applied in a range-extending application (i.e., as a generator), an LTC engine can work in a narrow operating area and increases the range of the battery pack.

Souk and Shahbakhti modified a turbocharged 2-liter GM Ecotec direct injection engine to function as a multi-mode LTC/Spark Ignition engine. The LTC modes included homogenous charge compression ignition (HCCI) and reactivity controlled compression ignition (RCCI) LTC engine.

Major changes to the base engine included:

- design and programming of a new Engine Control Unit (ECU)
- the addition of a port fuel injection system
- the capability to adjust intake temperature, pressure, and dilution level through the use of an intake air heater, supercharger, and Exhaust Gas Recirculation (EGR) rate modulation, respectively.

The engine functions as a generator for the battery pack.

Optimization results showed that in the UDDS driving cycle, the single-mode HCCI and RCCI engines offer 12% and 9% fuel economy improvement, respectively over a single-mode SI engine in the REEV. These improvements increase to 13.1% and 10.3% in the HWFET driving cycle. This fuel economy improvement is reduced to 3% in comparison to a modern CI (i.e. diesel) engine in the HWFET driving cycle.

Simulation results showed that the LTC engine offers higher fuel economy improvement in more aggressive driving cycles (e.g., US06) compared to less aggressive driving cycles (e.g., UDDS).

The optimal control algorithm enhanced the fuel economy by 17.0% over the rule-based strategy in a hybrid electric vehicle integrated with an LTC engine.

Using a "multi-mode"—i.e., both HCCI and RCCI—instead of "single-mode" LTC engine in the REEV provided 2% more fuel economy improvement, depending on the type of the driving cycle. Reducing the mode-switching fuel penalty increased the fuel economy improvement beyond 2%.

Among the LTC modes, HCCI was the dominant engine operating mode. If the fuel penalty to the RCCI mode decreased by 95%, the engine operated near to 45% of its ON time in the RCCI mode.

The study also found that HCCI and RCCI were more favorable from the NVH considerations, compared to the SI engine. This is due to use of low engine speeds in the LTC modes.

The team will be presenting a new paper on their work at the SAE 2017 World Congress next year.

Resources

- Ali Solouk, Mohammad Shakiba-herfeh, Kaushik Kannan, Hamit Solmaz, Paul Dice, Mehran Bidarvatan, Naga Nithin Teja Kondipati, Mahdi Shahbakhti (2016) "Fuel Economy Benefits of Integrating a Multi-Mode Low Temperature Combustion (LTC) Engine in a Series Extended Range Electric Powertrain" SAE 2016-01-2361
