TECHNOLOGICAL ENERGY LEVERS FOR CONNECTED AND AUTOMATED VEHICLES

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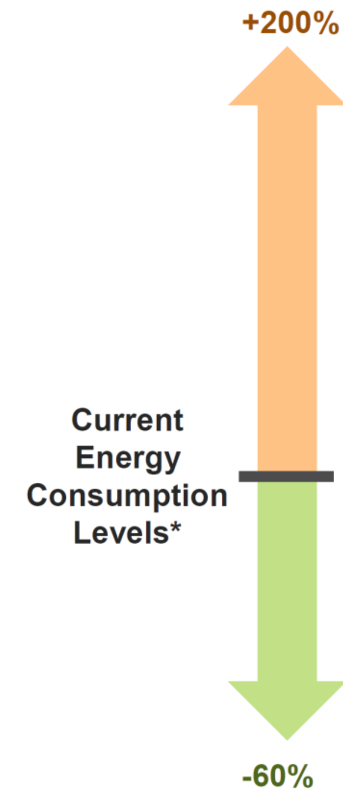
WHAT WILL AUTONOMOUS VEHICLES MEAN?

- Possible rapid changes in transportation sector in near future
- Megatrends and technology may lead to new paradigms



What is the impact on *energy*?

Image source: DOE, 2017.
https://www.energy.gov/eere/vehicles/downloads/transforming-mobility-ecosystem-report

DOE SMART MOBILITY

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

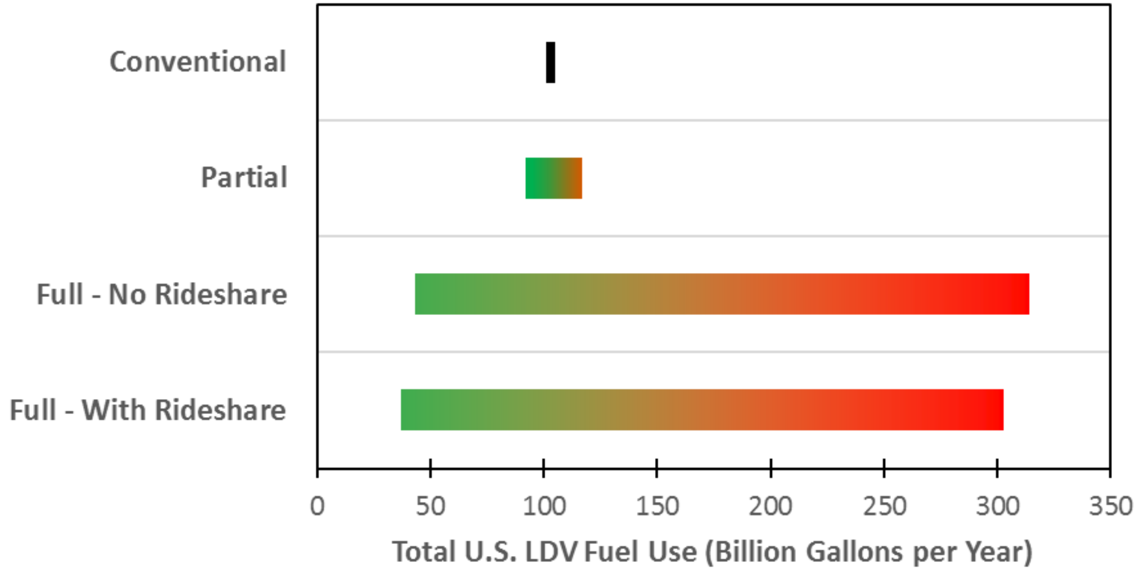
- Multi-lab consortium to answer research questions about new mobility paradigms
- Informs factors and scenarios for national-scale energy analysis

LIGHT-DUTY VEHICLE ENERGY CONSUMPTION

- How much energy are vehicles using / how much fuel are vehicles consuming?

$$\text{Energy} = \text{Demand} \times \text{Efficiency} = \frac{VMT}{MPG}$$

ESTIMATED BOUNDS OF FUEL USE BY CAVS



Source: Stephens et al., 2016. https://www.osti.gov/biblio/1334242

- Partial automation (~SAE level 2): ± 10–15%
- Full automation (~SAE level 4-5): -60% / +200%
- Ride-sharing: Reduction of up to 12%

WHAT FACTORS WILL IMPACT ENERGY USE?

Demand

Personal mobility	1	Shifting travel patterns - sprawl	
	2	Shifting travel patterns - urbanization	New
	3	Additional travel - underserved	
	4	Additional travel - leisure travel	New
On-road travel	5	Mode shift to highway	
	6	Re-routing (eco-routing)	New
	7	Ridesharing	
	8	Empty VMT (deadhead)	
	9	Additional fueling trips	New
Commerce	10	Efficient parking	
	11	Change in shopping trips	New
	12	Commercially sponsored trips	New

Efficiency

Travel changes	13	Changes in congestion	
	14	Faster travel	
	15	Drive smoothing	
Connectivity	16	Platooning	
	17	V2X connectivity	
	18	Off-board computation & data centers	New
	19	Electronics power draw	New
Vehicle design	20	Aerodynamic drag (sensors)	New
	21	Engine downsizing	New
	22	Vehicle rightsizing	
	23	Vehicle lightweighting	New
	24	Vehicle upsizing (mobile lounges)	New

ELECTRONICS POWER DRAW

- Auxiliary load for CAVs electronics can be substantial, lowering fuel economy
- Recent research from Ford showed that computer can use up to 80% of the auxiliary power
  - Details in Gawron *et al.*, 2018. https://pubs.acs.org/doi/10.1021/acs.est.7b04576
- Recent research from Toyota found at 3kW auxiliary load, there may be more than 30% reduction in vehicle energy efficiency
  - Details in Hamza *et al.*, 2019. https://journals.sagepub.com/doi/10.1177/0361198119835508
  - See also talk by Jean Chu, Toyota

HARDWARE DESIGN ARCHITECTURES

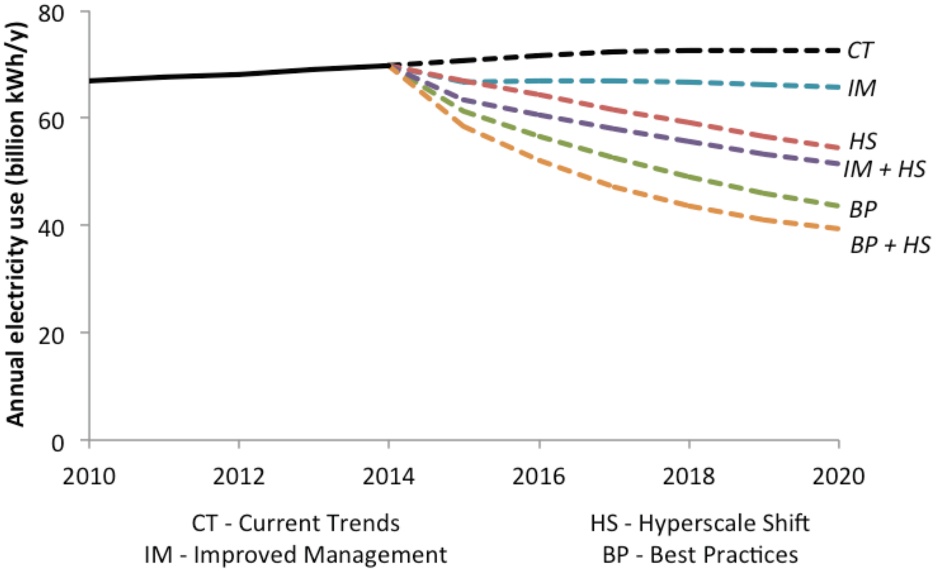
- Power can be minimized with specialized chips; latency major concern
- Recent research from the University of Michigan found that application-specific integrated circuits can reduce power load, but may still have latency issues.
  - Details in Lin *et al.*, 2018. https://doi.org/10.1145/3173162.3173191

PERFORMANCE VS. POWER

- Tesla presented custom-designed chip for self-driving vehicles
  - Details presented in Youtube video for Tesla Autonomie Day, online at https://www.youtube.com/watch?v=Ucp0TTmvqOE&t=5482
- Notable increase in visual computational capabilities, and modest *increase* in power draw

OFF-BOARD ENERGY REQUIREMENTS

- Not all computing will be on vehicle
  - "System critical" operations will
- Key off-board computational needs:
  - Dispatching & real-time routing
  - Data storage & recording
  - AI training
  - Traffic management
- Need to be cognizant of using best practices to minimize energy consumption by computer servers



Source: Shehabi et al., 2016.
https://eta.lbl.gov/sites/all/files/publications/lbnl-1005775_v2.pdf

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