The Future of Personal Mobility
Near-term Trends and Long-term Visions

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Global Climate & Energy Project
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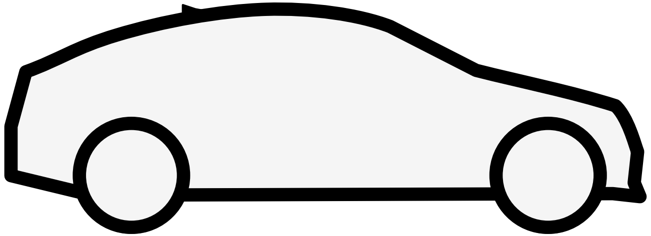
Automobile, Mobility … Why Not Just "Cars"?

Mobility =



Mobility Device

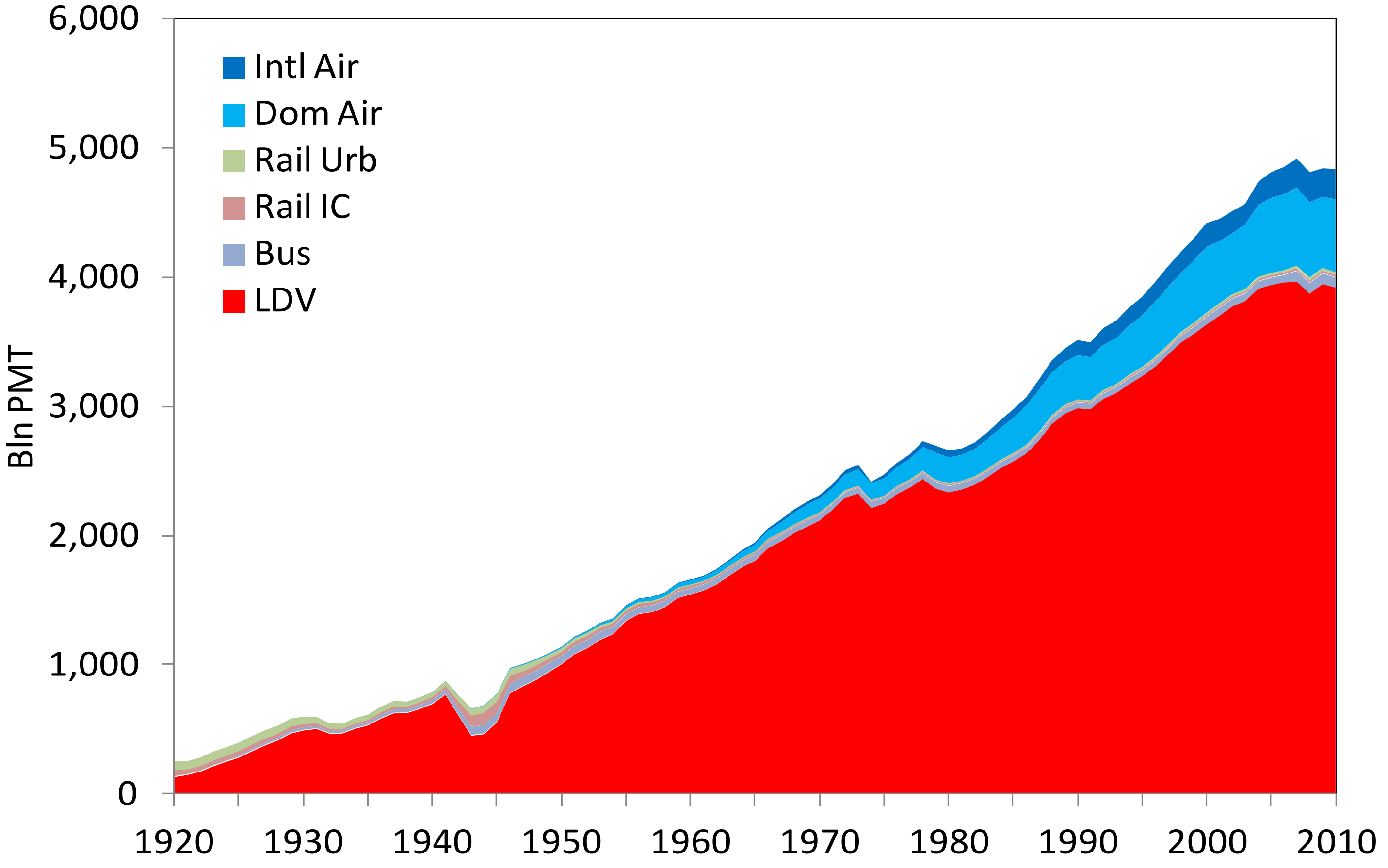
\+

…

Mobility Consumer

or: *Mobility = Transportation + Recreational Driving*

Personal Mobility = Usage of Automobiles



Source: U.S. Transportation and Energy since 1920", A. Schäfer, Sustainable Transportation Seminar, Stanford University, 09/14/2012

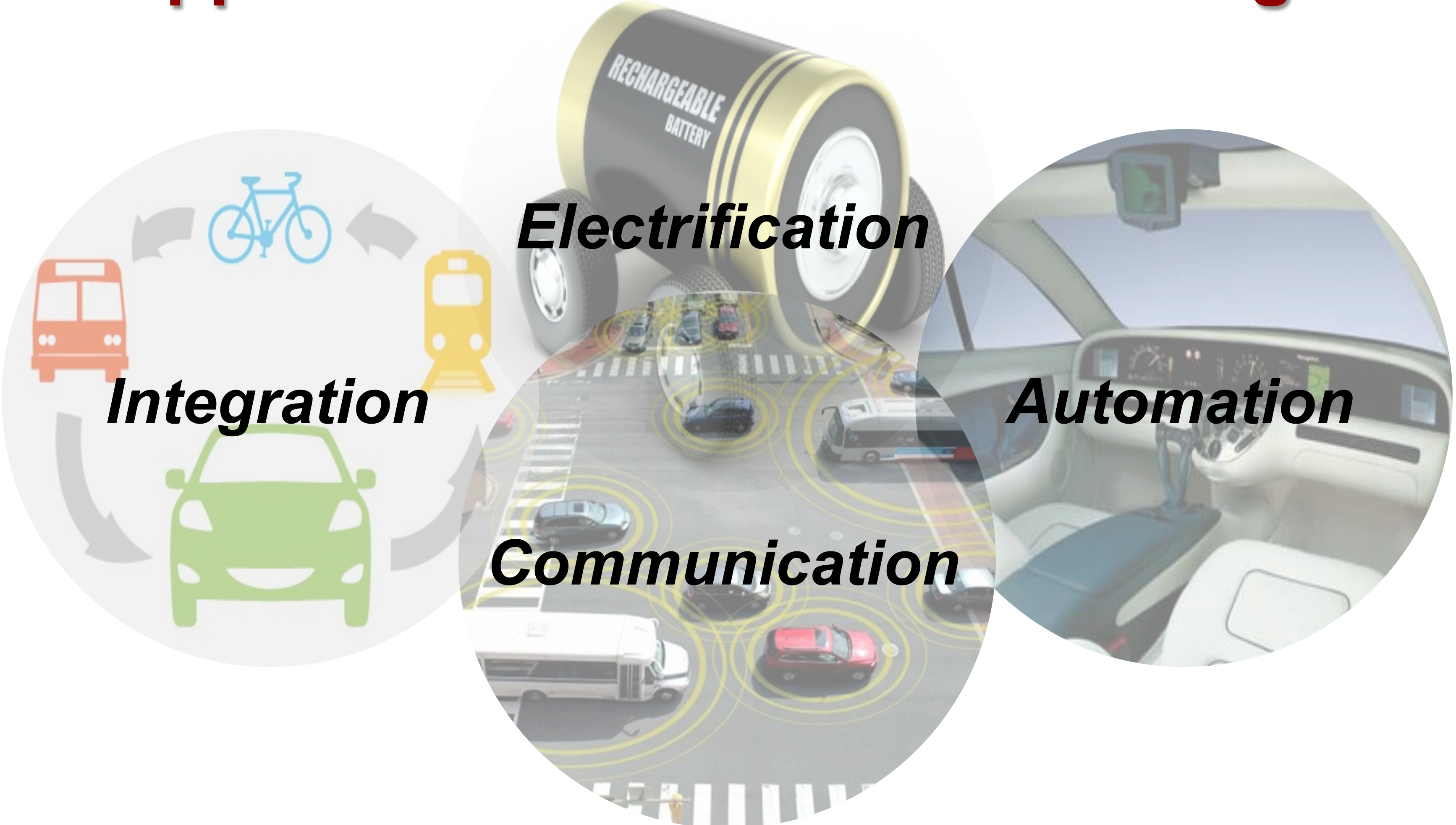
Problems Resulting from Personal Mobility

Accidents:	Motor vehicle crashes led to 34,080 fatalities in 2012[1], in 95% of the cases human error was at least a contributing factor[2]
Pollution:	Economic impact of health damages from motor vehicle emissions in the U.S. totals to over $40b (64b) per year[3]
Consumption:	9m barrel every day (10% of the global petroleum production) are consumed as gasoline in U.S. light duty vehicles[4]
Congestion:	Average commuter gets delayed 36 hrs per year due to congestion[5], 30% of inner city traffic due to parking search[6]




1. NHTSA, 2013; 2. NHTSA, 2008; 3.FHWA, 2000; 4. EIA, 2012; 5. TTI, 2009, 6. IBM 2011

Opportunities to Address Challenges



Opportunities to Address Challenges: Part 1

Electrification


-

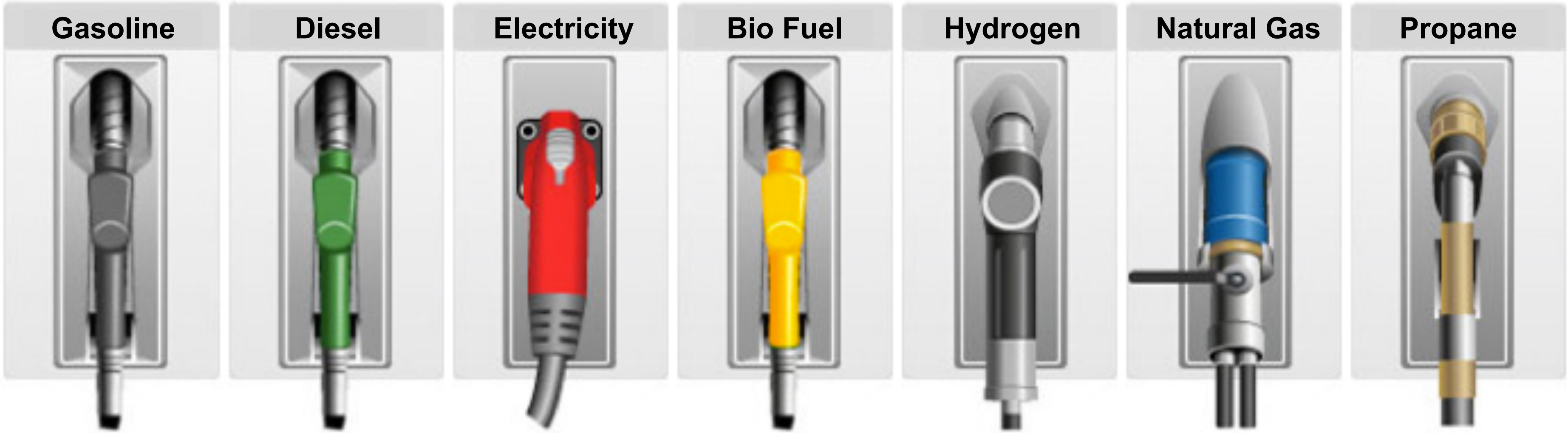

✓


✓


?

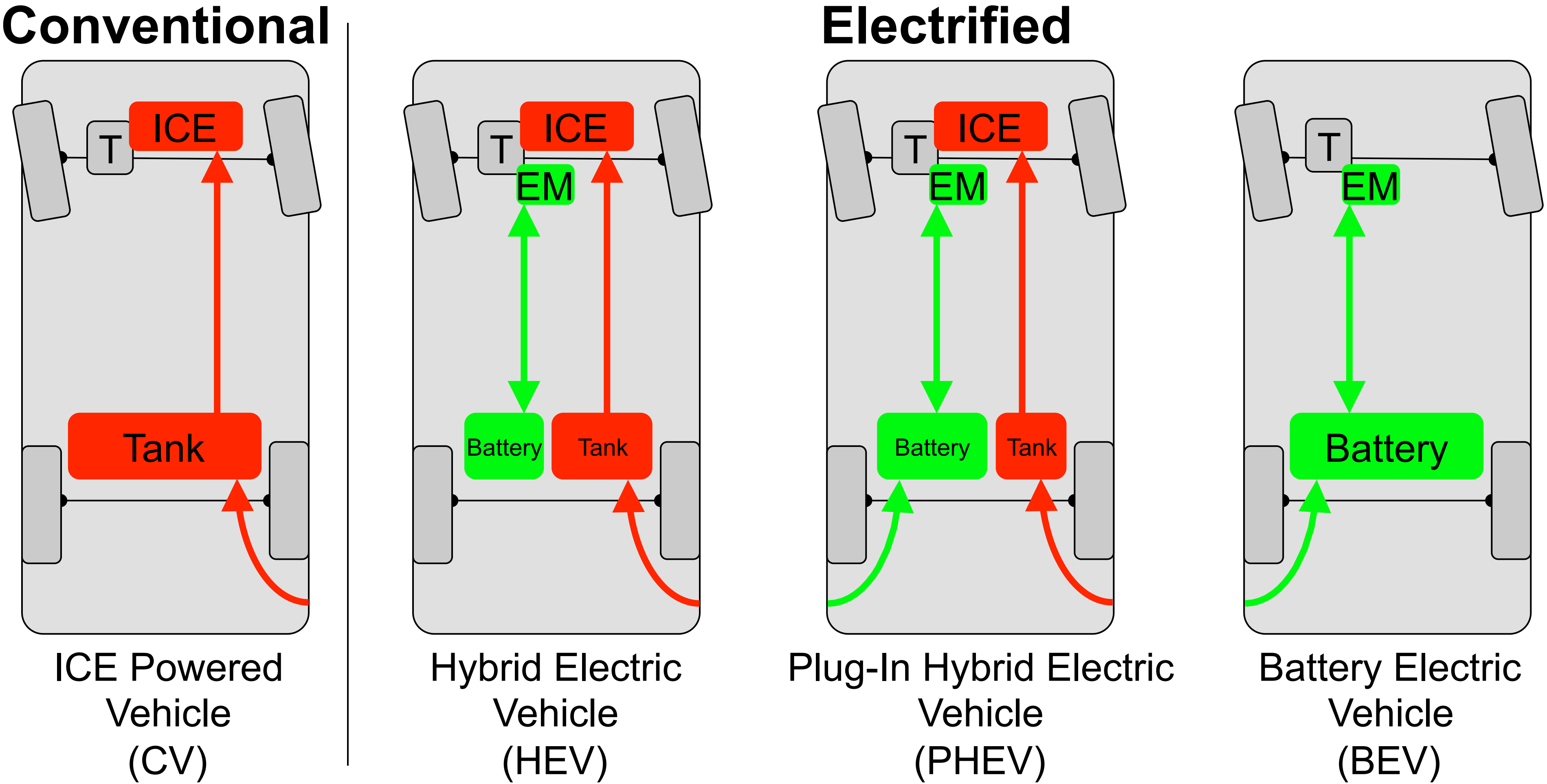
Electric components substitute / replace combustion engine & tank.

Overview Alternative Energy - Fuel Diversity



Source: http://www.afdc.energy.gov/ (adapted)

Different Levels of Vehicle Electrification



Focus on Vehicle Electrification

Under which conditions will electrified vehicles:

- **slow down global warming?**
- **decrease dependence on (foreign / scarce) resources?**
- **decrease air pollution?**
- **integrate into electric infrastructure?**
- **become the better alternative for consumers?**

➔ *There is (probably) not just one answer!*

Climate

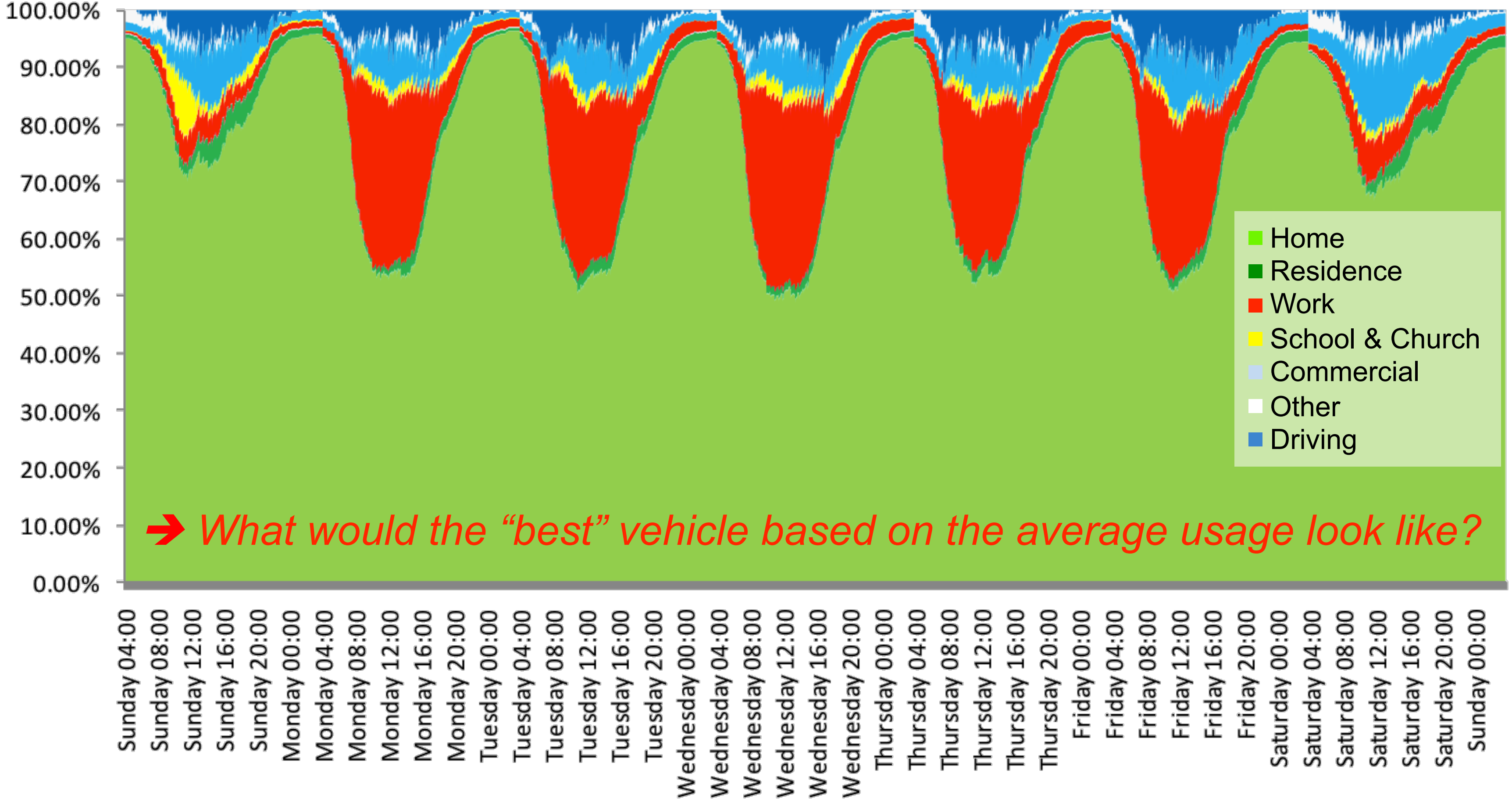
Resources

Pollution

Infrastructure

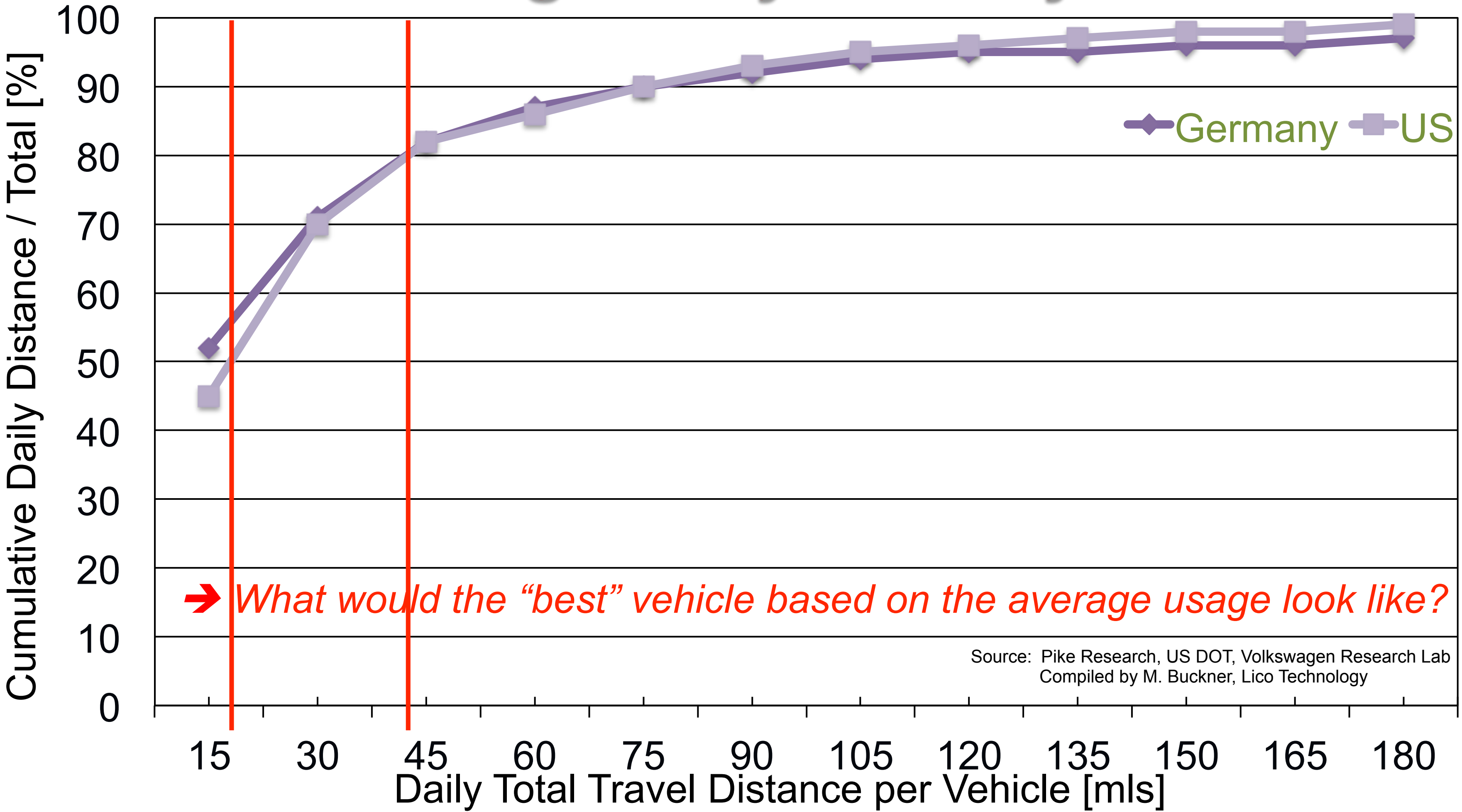
Consumers

Fleet Distribution – Where are the Vehicles?



Source: 2001 National Household Travel Survey ; GM Data Analysis (Tate/Savagian) - SAE paper 2009-01-1311

NHTS – Average Daily Mobility Behavior



Consumer Choice: Average vs. Extreme Case

Challenges for EVs – Range, Charge, Cost

Challenges US consumers see regarding electric vehicles [1]

28%   range and battery life
20%   availability of charging stations
17 % total cost/affordability
9%   high [purchase] cost of vehicles

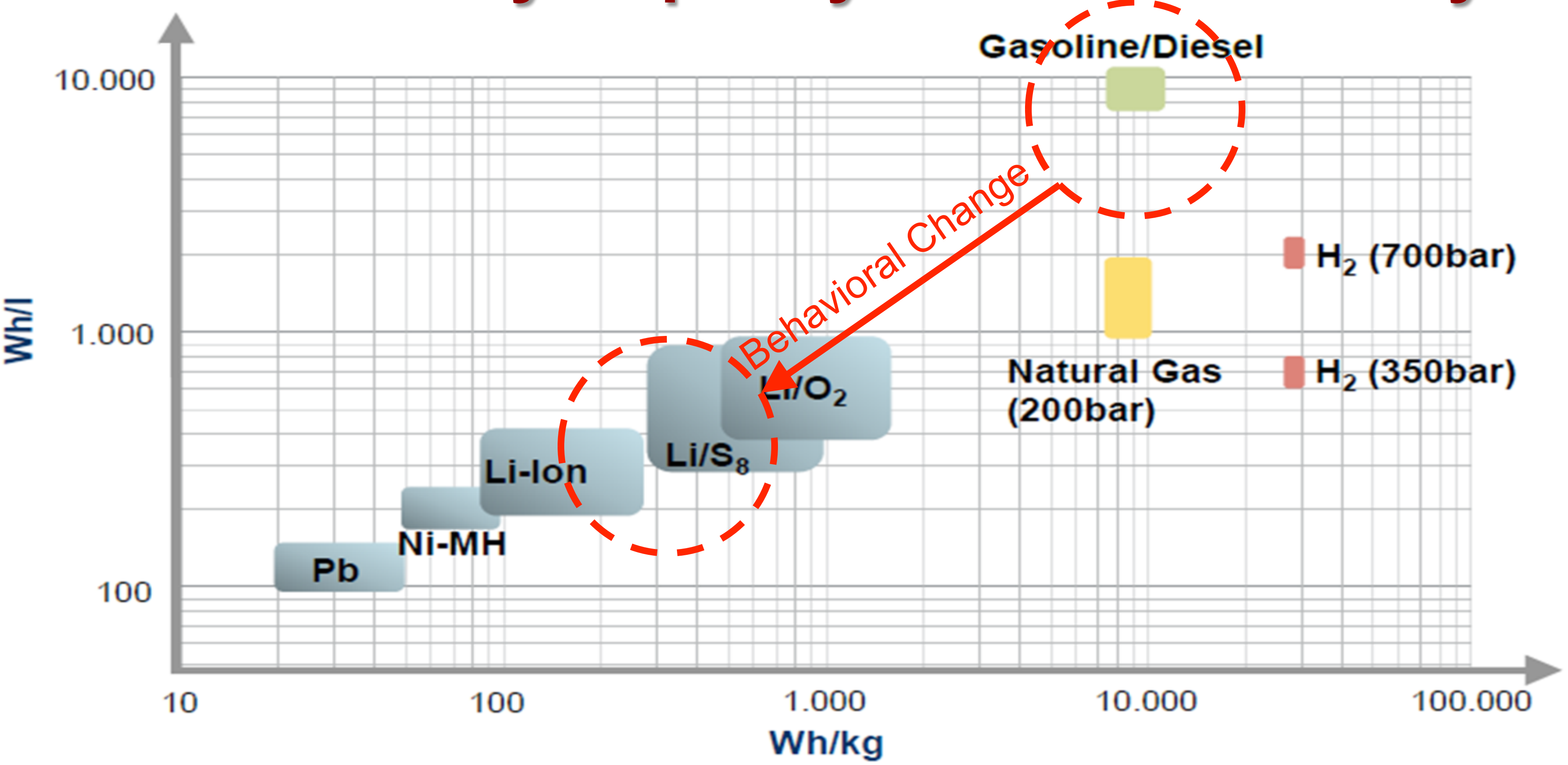
Challenges EU industry experts see regarding electric vehicles [2]

65%   range
57%   availability of charging stations
55%   total cost/affordability
30%   not suitable for everyday driving

Analysts expect EVs to have 2% to 3% share of the new-car market by 2020 [3]

[1] "Energy + Environment Study", Market Strategies International, Nov 2010 (1,168 interviews U.S. nationwide, Oct 14-25, 2010)
[2] "European Automotive Survey 2011", Ernst & Young, Aug 28, 2011
[3] "Are Americans Willing to Try Electric Cars?", The Wall Street Journal, Dec 1, 2010

More Battery Capacity = More Autonomy



Source: “Vehicles of the Future”, F. Leohold, Volkswagen Group Research, 2013

More / Faster Charging = More Autonomy

Type	Power supply	Voltage	Max current	Charge Time*
Level 1	Single phase - 1,9 kW	120 VAC	16 A	**12-16 hours**
Level 2	Single phase - 3,3 kW	230 VAC	16 A	**6-8 hours**
Level 2	Single phase - 7 kW	230 VAC	32 A	**3-4 hours**
Level 2	Single phase - 18 kW	230 VAC	80 A	**1-2 hours**
Level 3	Three phase - 10 kW	400 VAC	16 A	**2-3 hours**
Level 3	Three phase - 24 kW	400 VAC	32 A	**1-2 hours**
Level 3	Three phase - 43 kW	400 VAC	63 A	**20-30 min**
Level 3	Direct current - 50 kW	400-500 VDC	100 - 125 A	**20-30 min**
Level 3	Direct current** - 90 kW	480 VDC	200 A	**15 min**
Gasoline	Gas station - ≈10MW	--	20 l/min	**1 min**

Behavioral Change

*) Time to recharge 25kWh (≈ 75mls range), except “Gasoline” (≈ 300mls range)

**) Tesla Supercharger

Source: Wikipedia, Tesla Motors

Average Driving and Foregone Trips

Annual MPG /MPGe (Approximate)					
Persona#					
Persona1	49	60	72	skip 8 trips	skip 3 trips
Persona2	49	71	70	skip 5 trips	skip 5 trips
Persona3	50	105	99	106	97
Persona4	50	59	73	106	97
Persona5	49	61	85	skip 3 trips	skip 3 trips
Persona6	49	62	90	skip 2 trips	skip 2 trips
Persona7	50	53	49	skip 54 trips	skip 5 trips
Persona8	50	67	99	106	97
Persona9	50	56	61	skip 5 trips	skip 1 trip
Persona10	50	53	49	skip 138 trips	skip 46 trips

1: urban dweller no commute by car, weekend trips 200mls, vacation 350mls
2: photographer, coaches students, visits son in Davis quarterly
3: teacher 20mls commute, run errands 10mls
4: employee 50mls commute, weekend at family villa 100mls
5: employee 60mls commute, weekend errands 15mls, vacation 300mls
6: employee 36mls commute, weekend errands 15mls, vacation 350mls
7: sales person 90-145mls p. day, vacation 300mls
8: employee 50mls commute, weekend errands 15mls, vacation 80mls
9: employee with 40mls commute, shuttle kids 60, vacation 300mls
10: consultant commute 45 / 150 / 300mls, weekend 40mls

Challenges for EVs – Range, Charge, Cost

Challenges US consumers see regarding electric vehicles [1]

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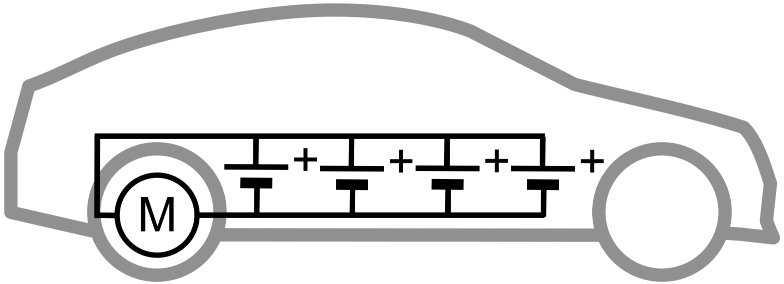
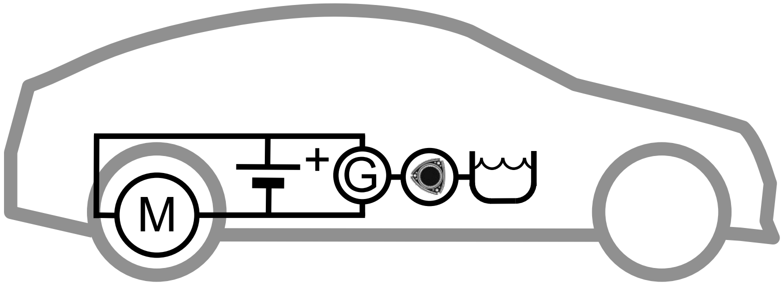
[3] "Are Americans Willing to Try Electric Cars?", The Wall Street Journal, Dec 1, 2010

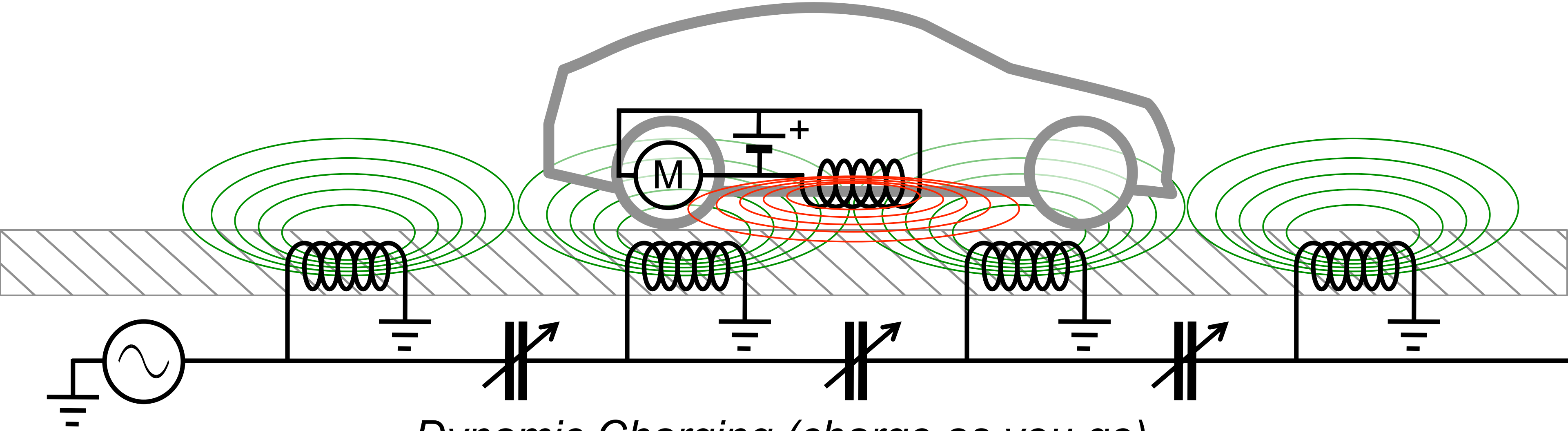
The Range Solution – Today and Tomorrow



Larger Battery (a little extra charge)



Range Extender (onboard generator)

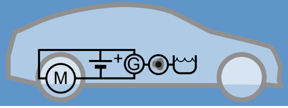
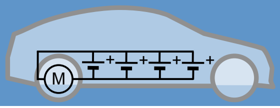


Dynamic Charging (charge as you go)

Covering "Perceived Need" w/ Low Weight

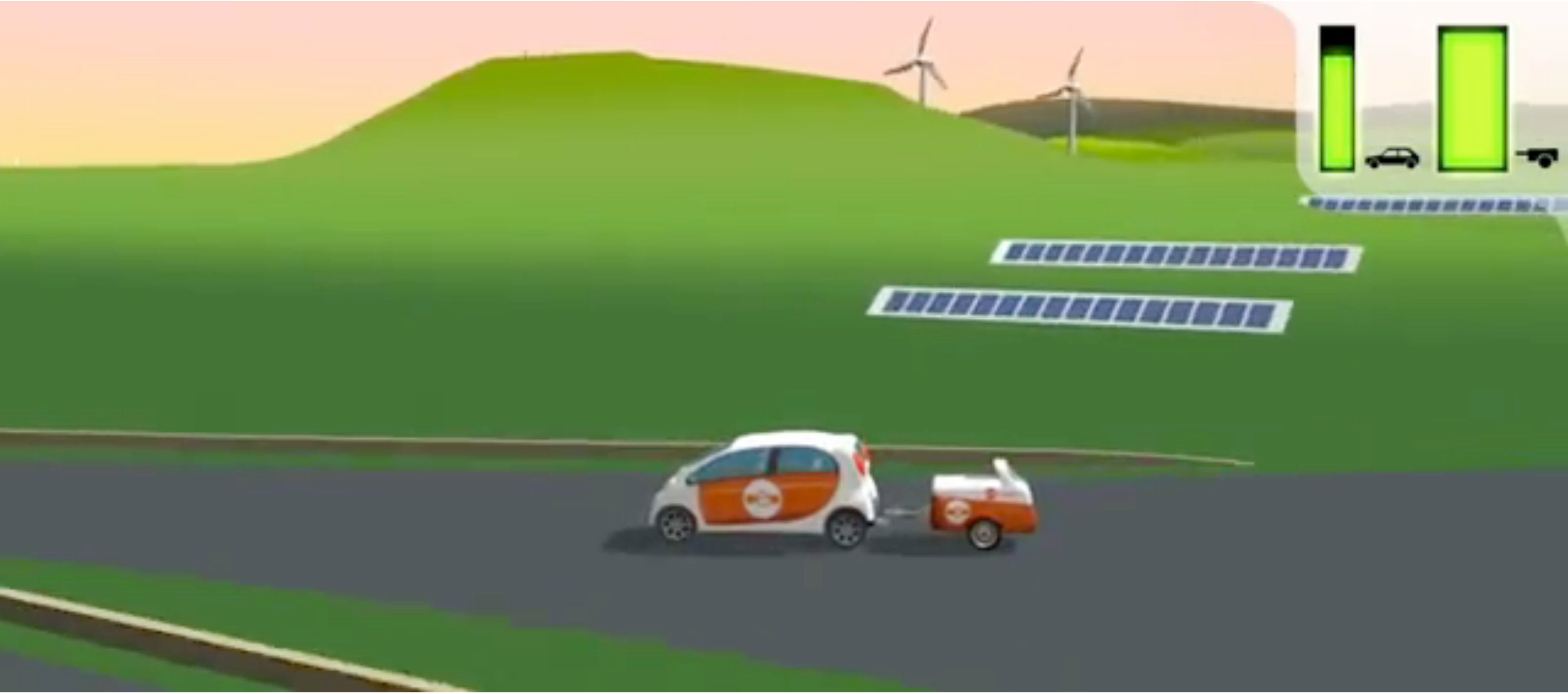
Assumption: Daily commute is 40 mls round trip and doing that electrically is the "cleaner" option, but consumers want to have peace of mind that they can drive 300 mls with their vehicle without "complicated" recharging

Question: What is the "lightest" option for the extra 260 mls?

	Gasoline Range Extender 	Larger Battery Pack 
Range (miles)	260	260
Energy Required (kWh)	66.3	66.3
Efficiency	0.4 x 0.85	-
Gasoline / Battery Weight (kg)	15.5	522.4
Equipment Weight (kg) engine, fuel system, exhaust	117	-
Total Additional Weight (kg)	**132.5**	**522.4**

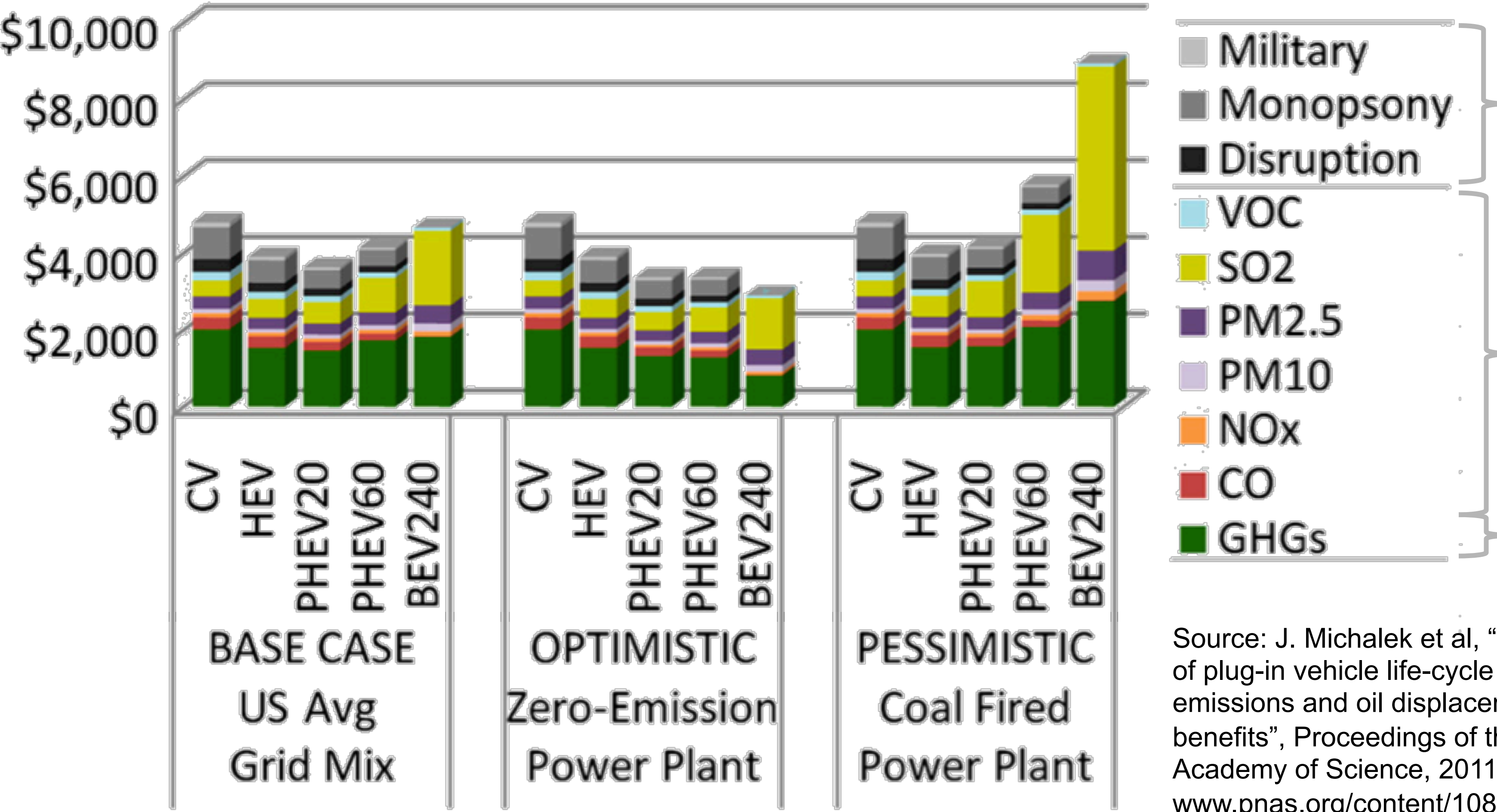
Source: S. R. Ganapathy, "Electrification of Vehicles", Independent Study, Stanford University, 2011

Alternative Range Solution: Battery Trailer



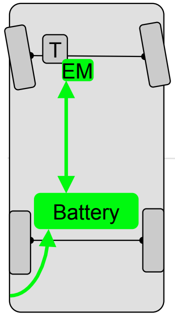
Source: http://www.youtube.com/user/ebuggy01

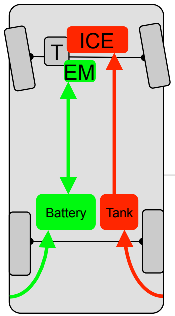
Lifetime Externalities for Electrified Vehicles



Source: J. Michalek et al, "Valuation of plug-in vehicle life-cycle air emissions and oil displacement benefits", Proceedings of the National Academy of Science, 2011 - http://www.pnas.org/content/108/40/16554

PEV vs. BEV – A Minimum Winning Game?

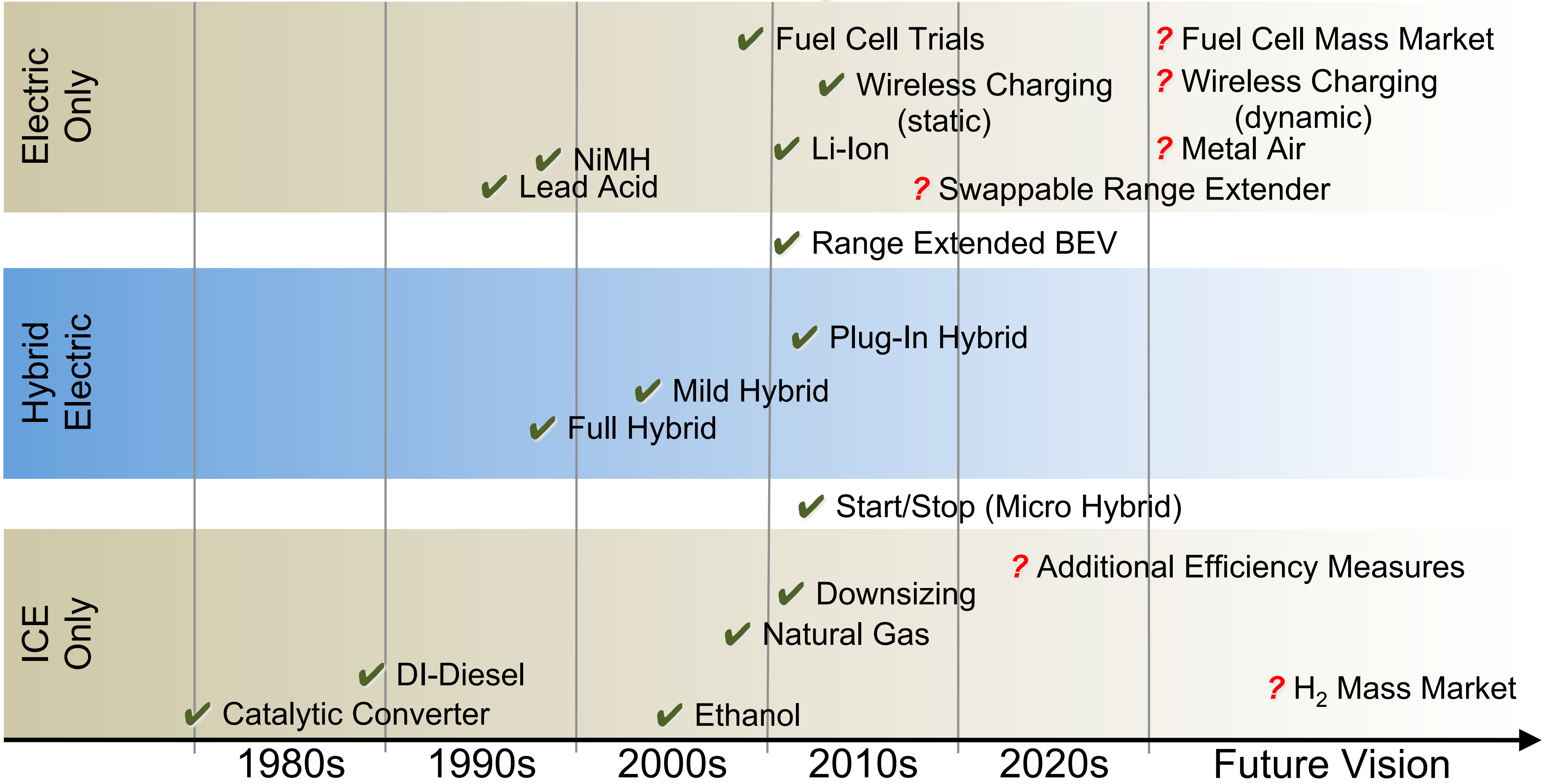




	Consumer	Manufacturers	Utilities	Environment
Battery Only Electric	?	?	?	?
Plug-In Hybrid Electric	✔	?	✔	?

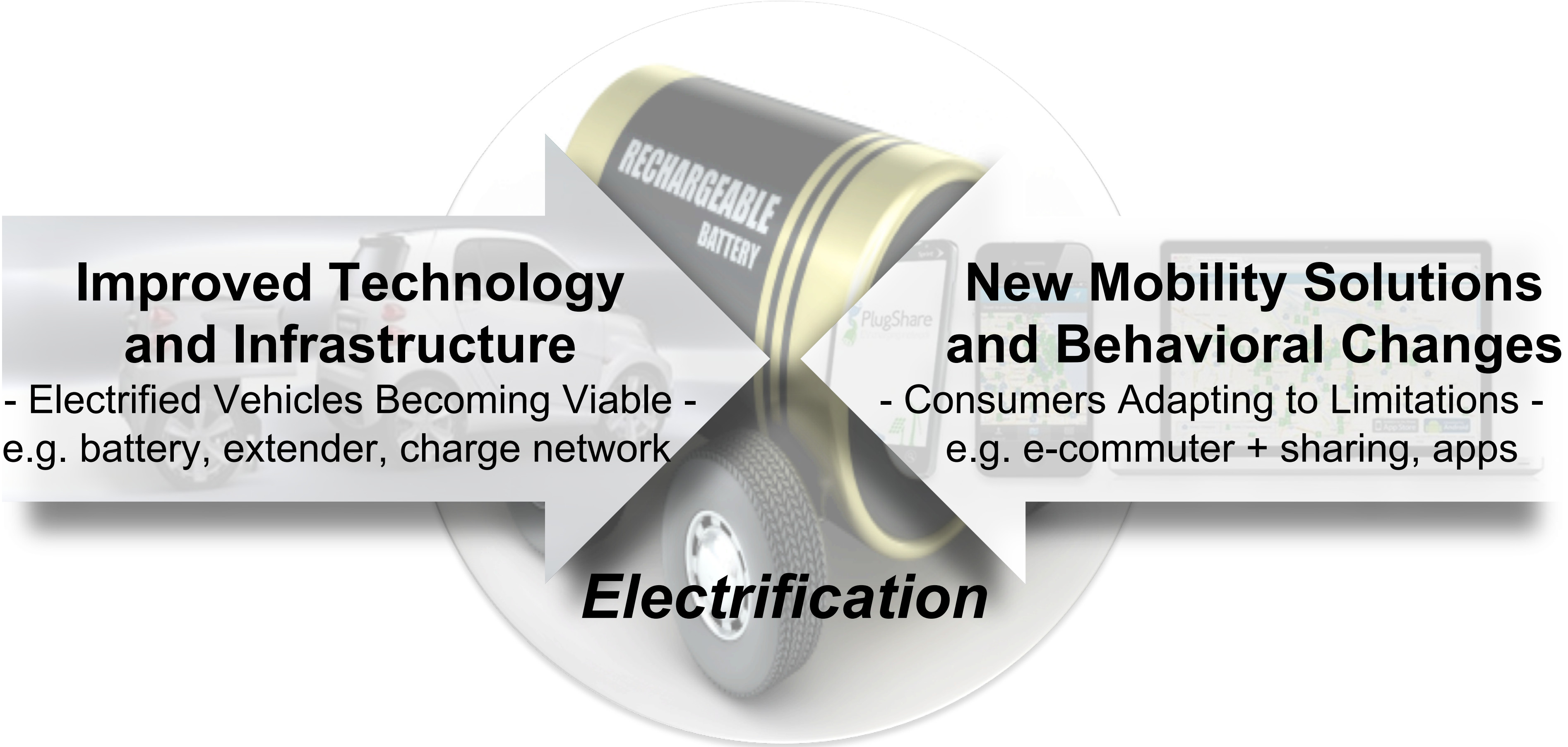
Expectation: Shift from BEV to PHEV and REV

Outlook: From Liquid to Electric



Source: Author’s own observation, except [1]:http://www.eia.gov/oiaf/aeo/tablebrowser/, reference case 2035, EIA, 2013

Two Main Trends in Electrification



Opportunities to Address Challenges: Part 2


✓


?


?


?

Computer takes over (in part) driving task from human.

Definitions for Automated Vehicles

NHTSA level	SAE level	SAE name	SAE narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Backup performance of *dynamic driving task*	System capability (*driving modes*)
	***Human driver* monitors the driving environment**						
0	**0**	**Non-Automated**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**1**	**Assisted**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**2**	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
	***Automated driving system* ("system") monitors the driving environment**						
3	**3**	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**4**	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
	5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Source: Summary of SAE International's Draft Levels of Automation for On-Road Vehicles, July 2013

Focus on Automated Driving

Under which conditions can automated vehicles:

- **become affordable for mainstream consumers?**
- **make people feel safe and comfortable while being driven?**
- **release the driver from the need to monitor the car?**
- **interact with human controlled vehicles?**
- **be deployed without massive infrastructure investments?**

➔ *Vision and reality might be worlds apart!*

Consumers

Trust

Liability

Interaction

Independence

Stanford's Prof. Thrun's Automated Car, 2007

Stanford's Prof. Gerdes' Automated Car, 2012

Google's Automated Car, 2012

Source: Google

The Vision of Automated Driving

The Reality of Automated Driving

Legal Situation for Automated Vehicles

The Situation is:

- ❑ Nevada, Florida, and California are currently the only states to expressly regulate "autonomous vehicles"
- ❑ Legislators or regulators in many states are aware of and interested in this topic
- ❑ Lobbying determines the fate of these bills

The Situation is NOT:

- ❑ ~~These three states have "legalized" autonomous vehicles~~
- ❑ ~~These vehicles are illegal elsewhere~~
- ❑ ~~The legal status of autonomous vehicles is entirely clear in any state~~

Source: "*State of the States on the State of the Art*", Bryant Walker Smith, 12/5/2012

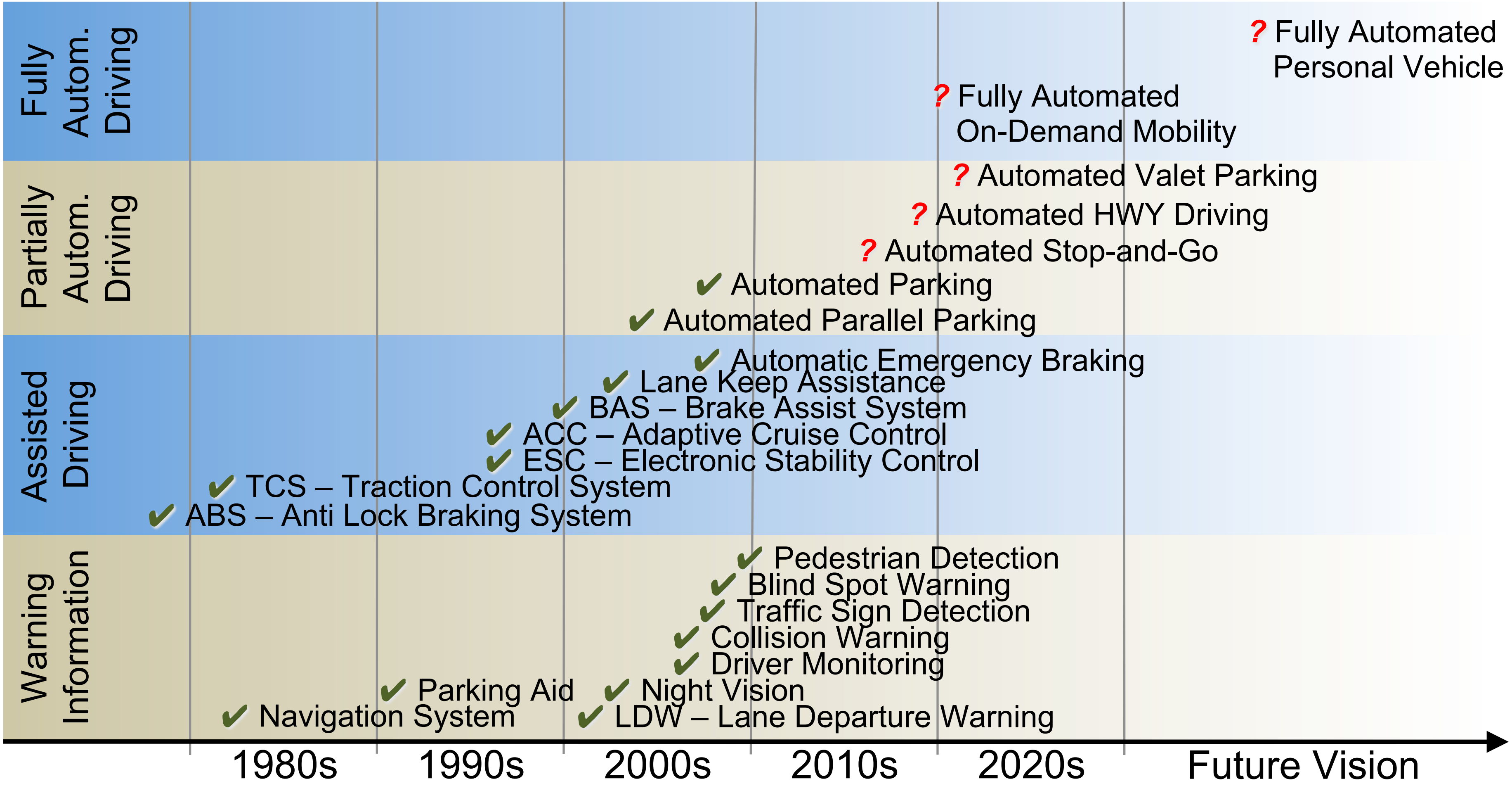
Other Automated Ground Vehicles

Consumer and Commercial Equipment

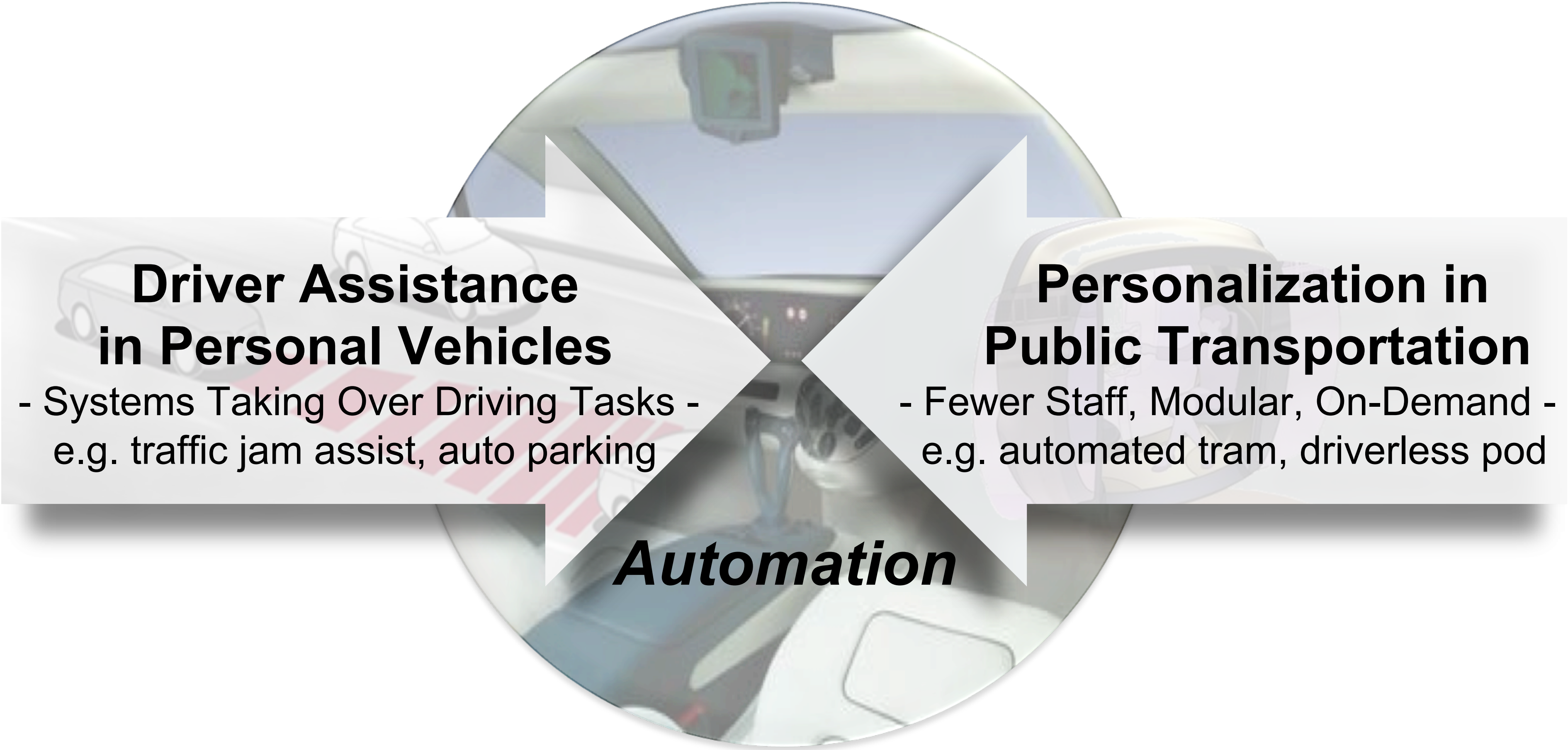
Public and Private Shuttle Systems

Agricultural and Mining Vehicles

Outlook: From Assistance to Automation



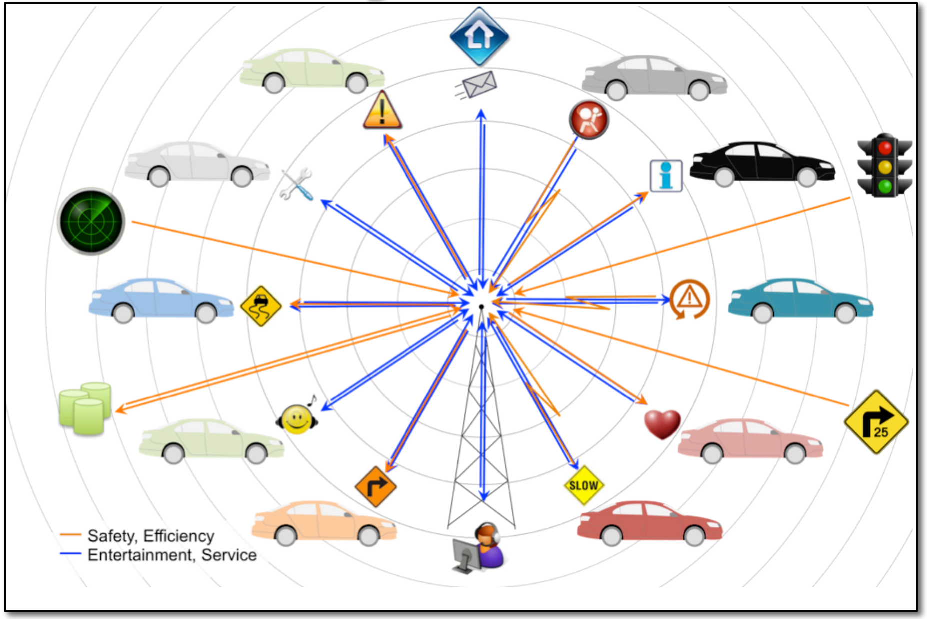
Two Main Trends in Automation

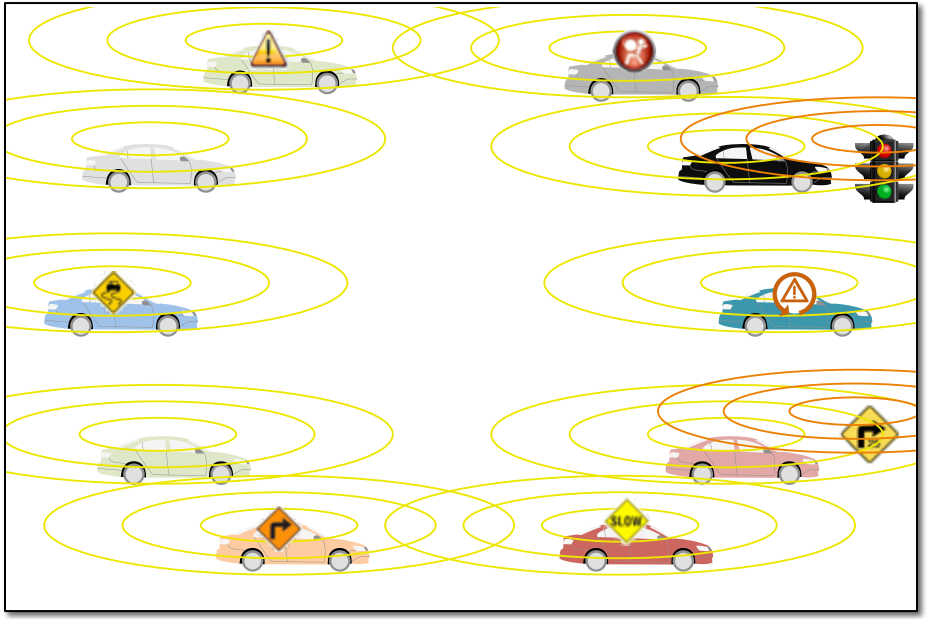


Opportunities to Address Challenges: Part 3

Vehicles communicate with one another and with infrastructure.

Two Ways to Communicate - Cellular / DSRC





Public Cellular Based Communication

Pros: existing & evolving network + standards, coverage, cost

Cons: security, reliability, centralized base-station network

Dedicated Short Range Communication

Pros: security, reliability, decentralized ad-hoc network

Cons: no existing network, coverage for V2I very unclear, cost

Focus on Vehicle Communication

How can an online data connection to vehicles:

- **improve safety, efficiency by sharing data among vehicles?**
- **improve productivity, enjoyment without distraction?**
- **benefit from existing communication infrastructure?**
- **utilize crowd sourcing for mobility specific needs?**
- **enable a seamless and sustainable mobility experience?**

➔ *The internet is already in the car – but needs to be more integrated!*

Safety

Infotainment

Cellular

Crowd

Intermodality

How Smart is Your Car?

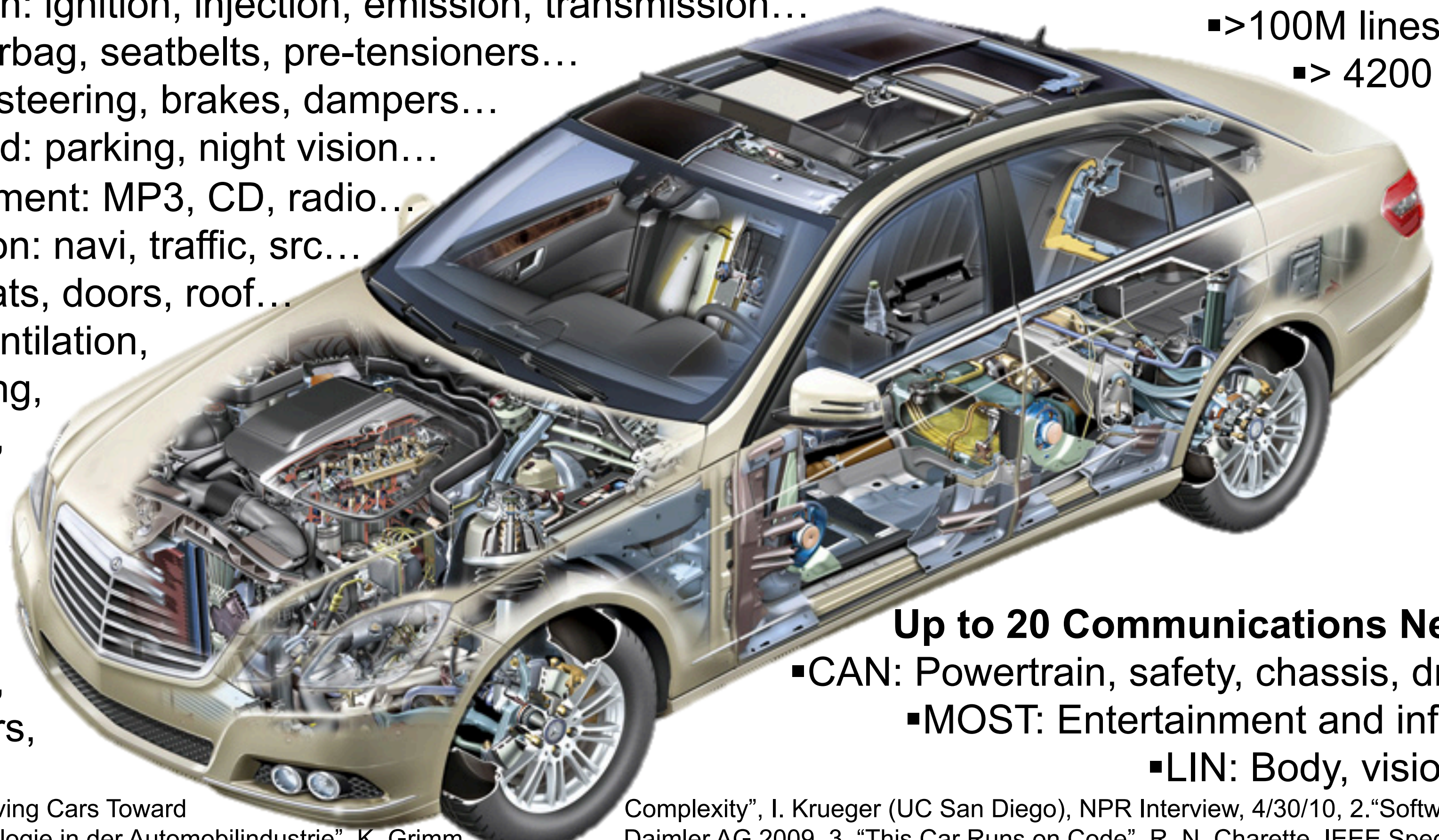
Smart Phone

Dumb Car?

Modern Automobile – Really so Dumb?

Up to 80 controllers[1]

- Powertrain: ignition, injection, emission, transmission…
- Safety: airbag, seatbelts, pre-tensioners…
- Chassis: steering, brakes, dampers…
- Driving Aid: parking, night vision…
- Entertainment: MP3, CD, radio…
- Information: navi, traffic, src…
- Body: seats, doors, roof…
- Cabin: ventilation, heating, cooling, filtering, …
- Vision: lights, wipers, mirrors, …



Up to 35-40% of vehicle cost[3]

- >100M lines of code
- > 4200 signals[1]

Up to 20 Communications Networks[2]

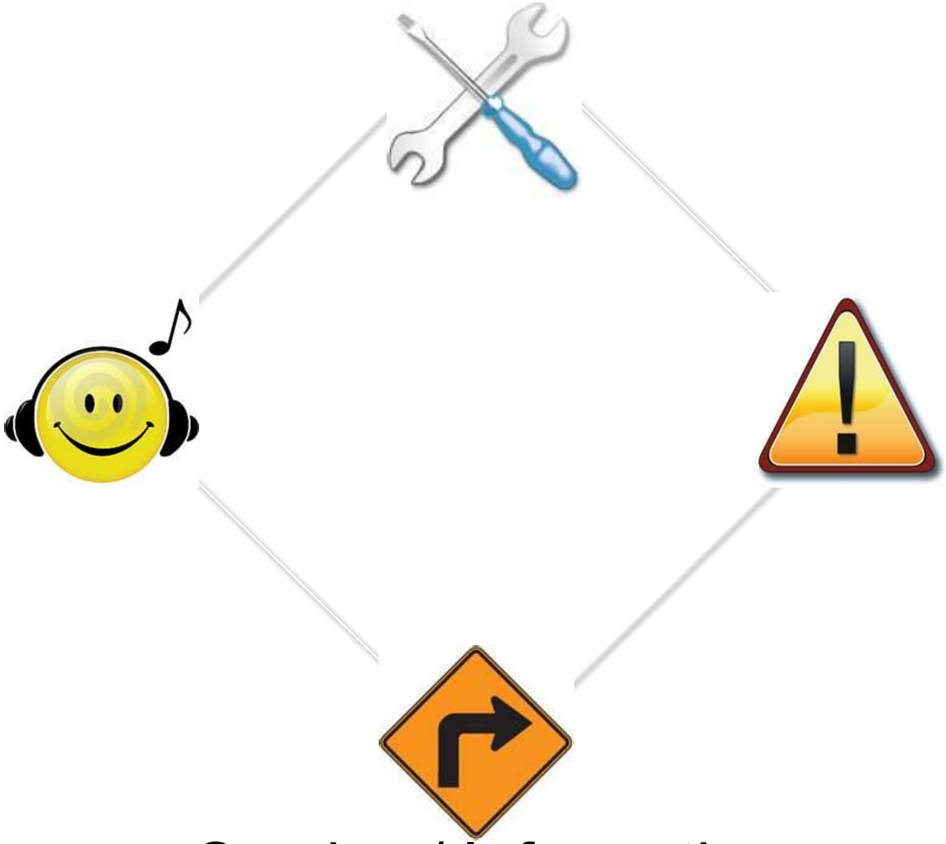
- CAN: Powertrain, safety, chassis, driving aid
- MOST: Entertainment and information
- LIN: Body, vision, HVAC

Sources: 1. “Driving Cars Toward Complexity”, I. Krueger (UC San Diego), NPR Interview, 4/30/10, 2.“Software-technologie in der Automobilindustrie”, K. Grimm, Daimler AG,2009, 3. “This Car Runs on Code”, R. N. Charette, IEEE Spectrum, 2/11/13

Different App Categories for Internet of Cars

Maintenance / Repairs

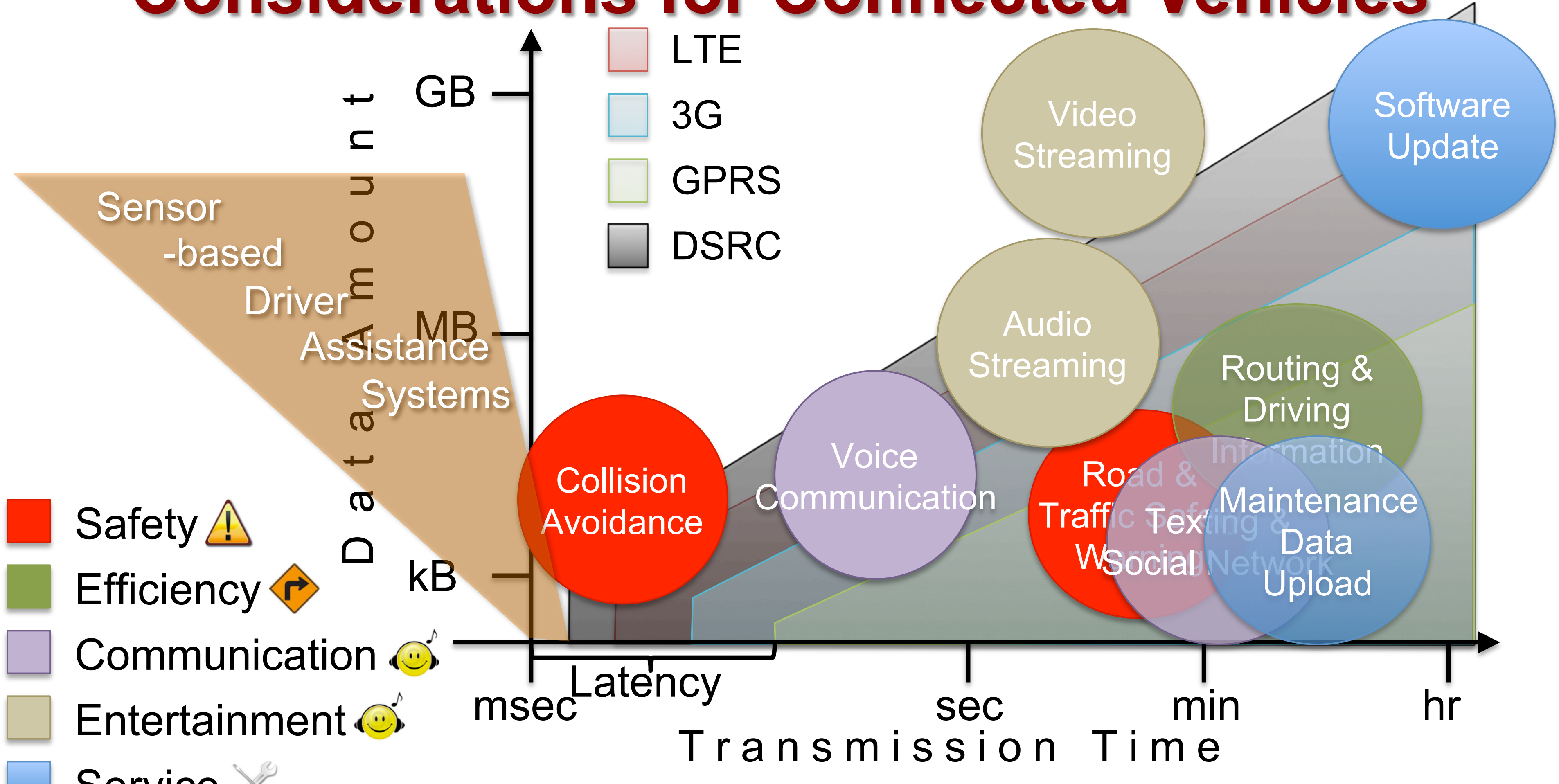
Entertainment / Communication



Safety / Efficiency

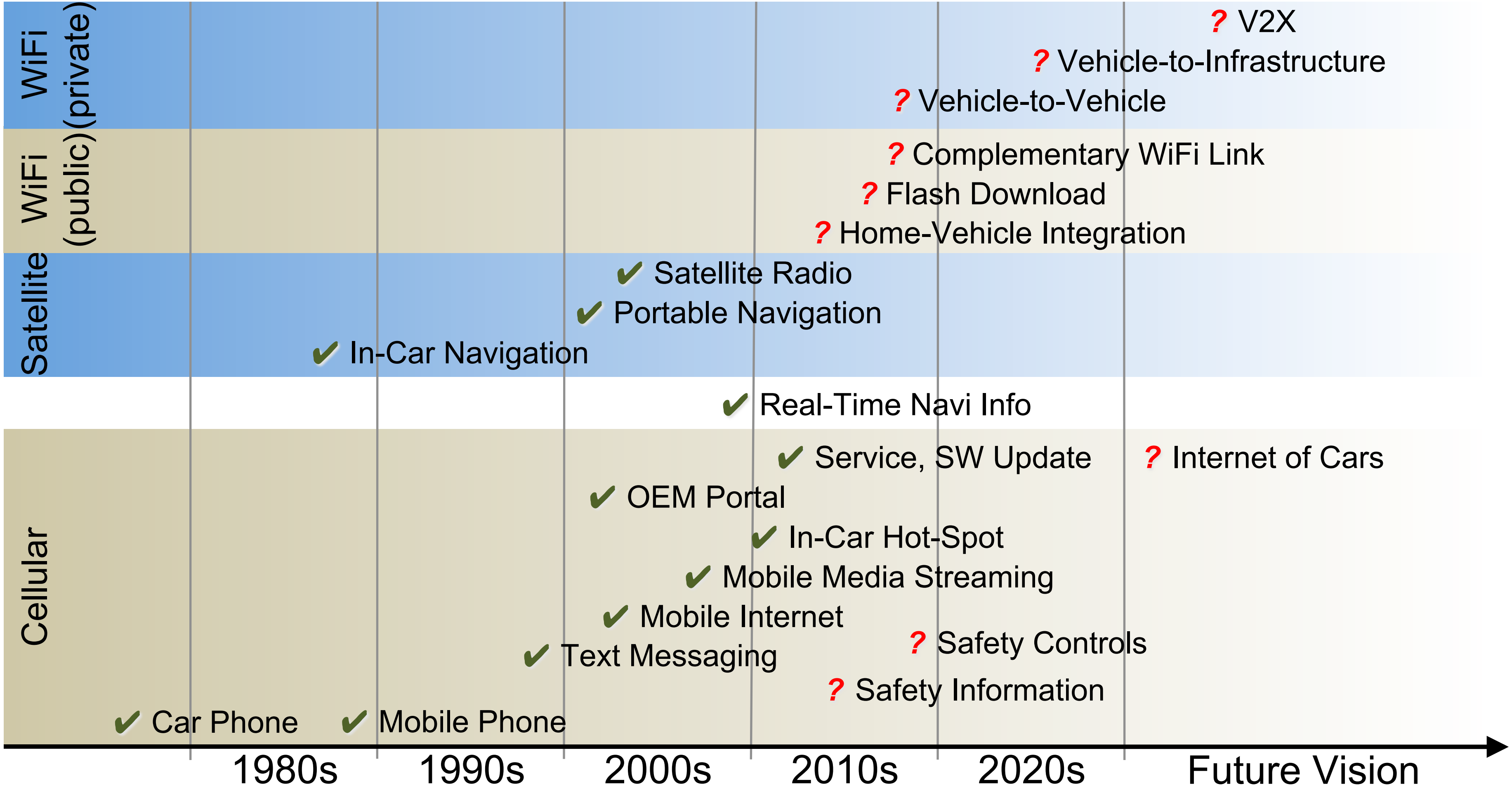
Service / Information

Considerations for Connected Vehicles



Author’s depiction, only for qualitative comparison

Outlook: From P2P to M2M



Two Main Trends in Communication

Opportunities to Address Challenges: Part 4

Automobiles become integral part of an intermodal mobility system.

Focus on Mobility Integration

Which relationship will consumers have with their vehicles regarding:

- **access to vs. ownership of an automobile?**
- **the automobile as status symbol?**
- **new needs for the aging society?**
- **new values of the young generation?**
- **impact of mass motorization in emerging countries?**

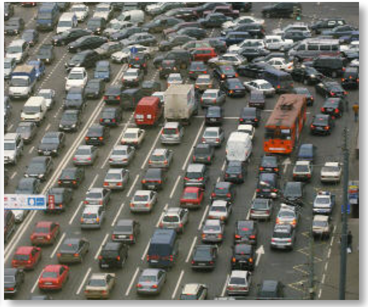
➔ *Considerations depend heavily on regional differences!*

Ownership

Status

Aging Society

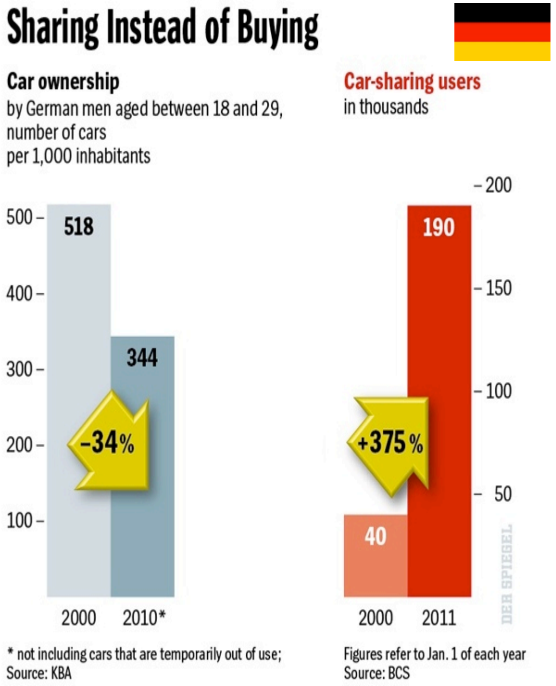
New Values



Car Boom

Decreasing Interest in the Automobile?

- **1978 in US**
  - 50% of 16-year-olds had driver's license
  - ~12 M teenagers total had license
- **2010 in US**
  - 30% of 16-year-olds had driver's license
  - ~10 M teenagers total had license



NOVEMBER 20, 2011

Disruptions: For Teenagers, a Car or a smartphone?

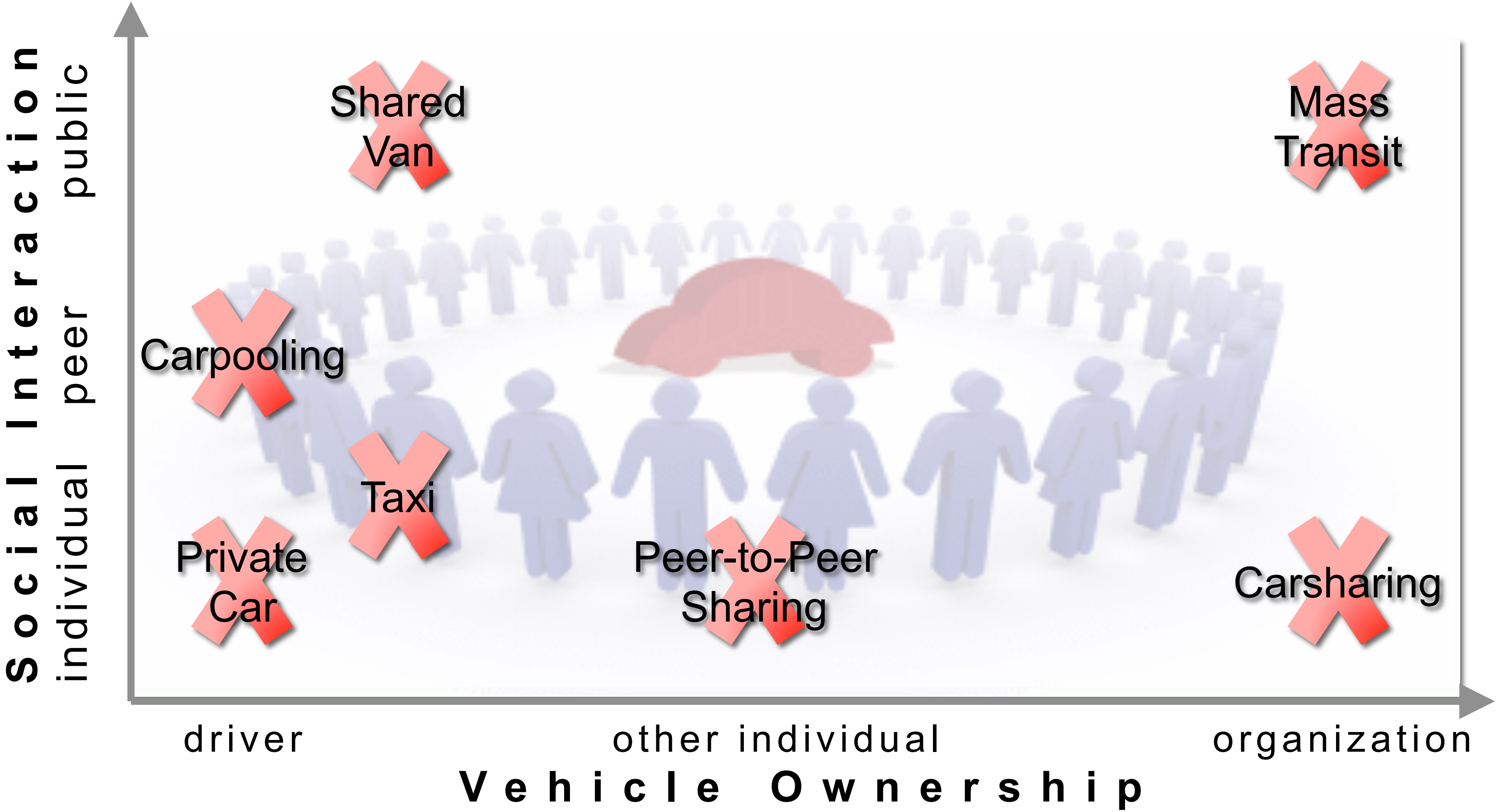
The New York Times

AUGUST 6, 2013

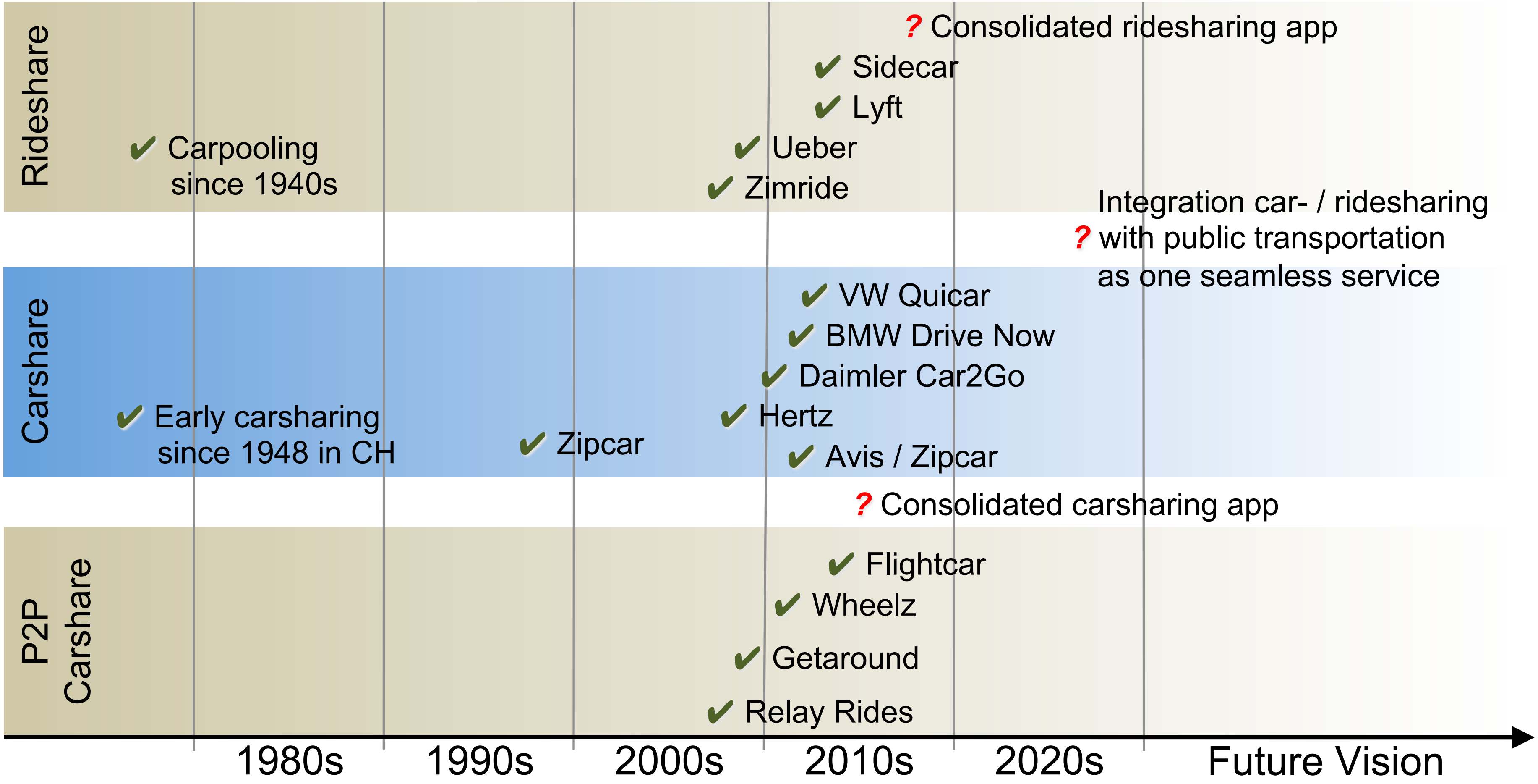
Auto industry predicts younger people will buy cars again once finances improve

The Washington Post

Mobility Solutions – Many Different Options



Outlook: From Freedom to Care-Free



Two (One?) Main Trend(s) in Integration

Automobile Stays Symbol of Independence and Personality

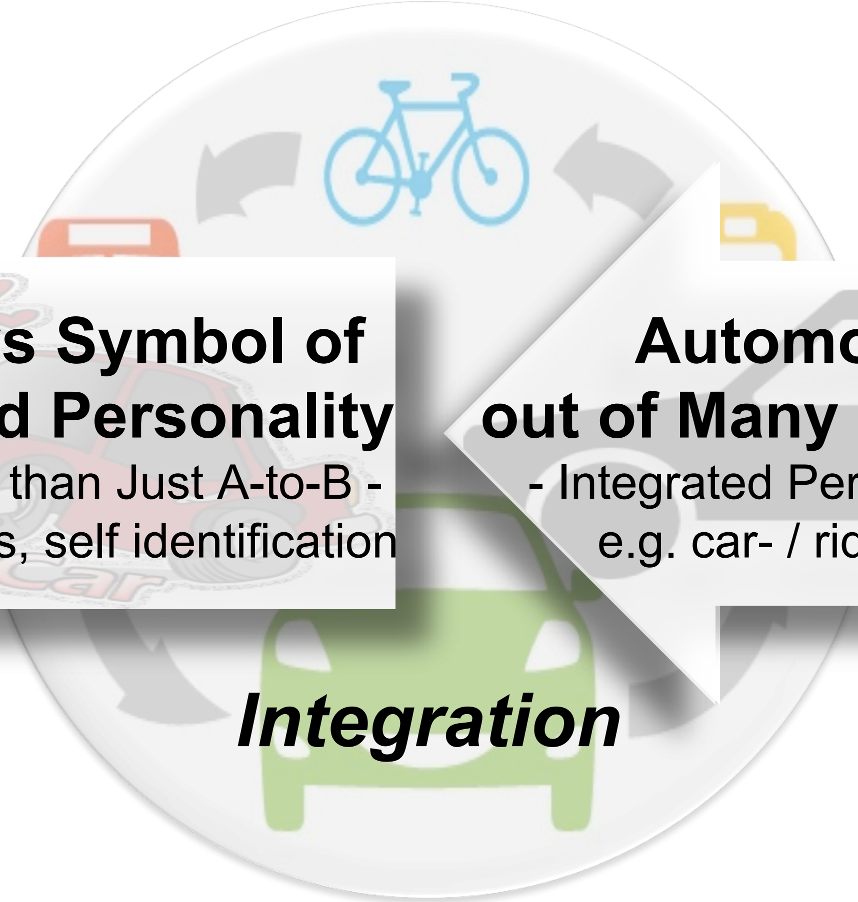
- Personal Mobility More than Just A-to-B -

e.g. personalized vehicles, self identification

Automobile Just One out of Many Mobility Options

- Integrated Personal / Public Mobility -

e.g. car- / ridesharing, on-demand



Summary: The Future of Personal Mobility

Electrification

- ✓ Technology is evolving to enable long-distance travel with EVs
- ? Consumer adoption and infrastructure deployment unclear
- ➔ Deployment path: range extender > improved battery > infrastructure

Automation

- ✓ Technology would be ready to automate vehicle control very soon
- ? Mix of standard and automated vehicles imposes many challenges
- ➔ Deployment path: stop&go > hwy > parking > dedicated lanes > A-B

Communication

- ✓ Technology would be ready to connect vehicles with one another
- ? Cost for dedicated vehicle-infrastructure communication network immense
- ➔ Deployment path: X2V cellular > V2V WiFi > V2X multi-standard

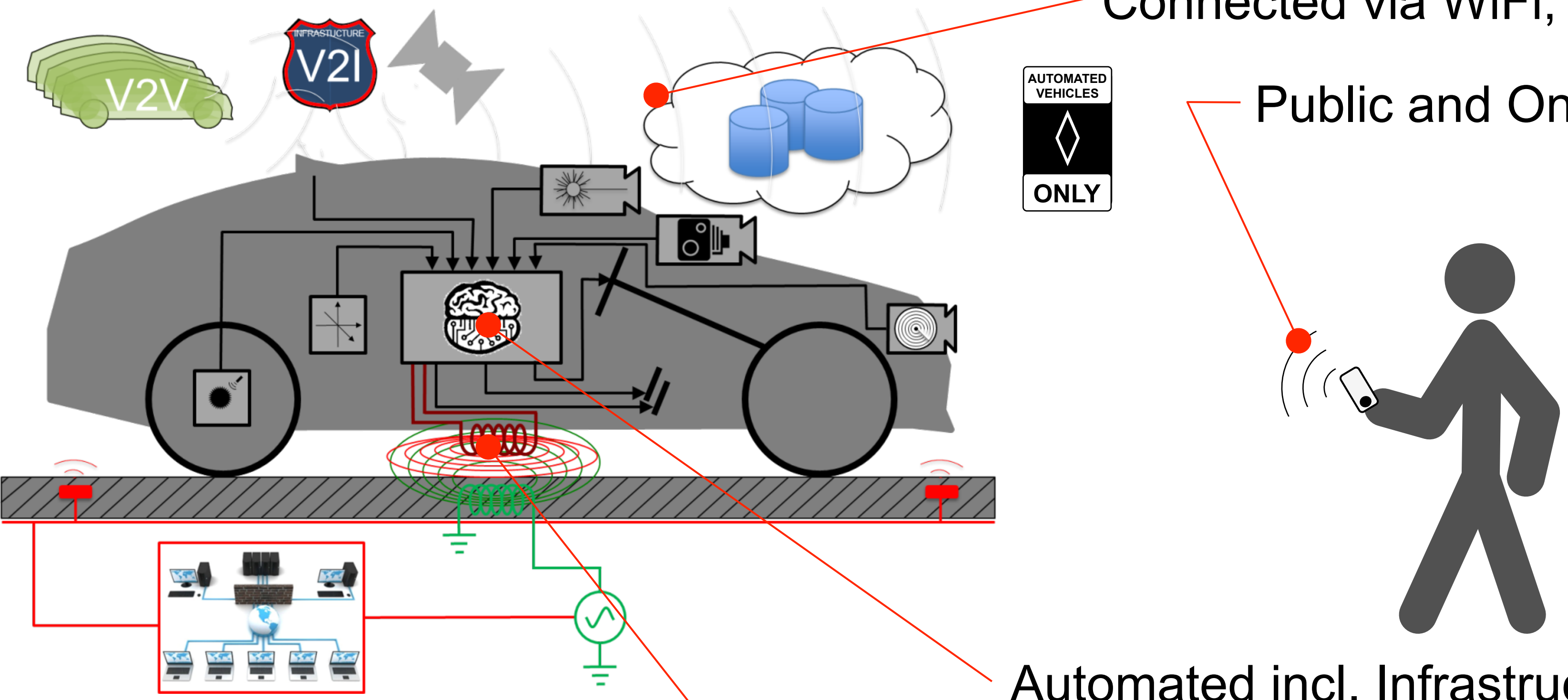
Integration

- ✓ Alternative transportation systems evolve, especially sharing opportunities
- ? Automobile’s dominance continues because of its flexibility / independence
- ➔ Deployment path: car / ride sharing > integration personal-public transport > multi-modal mobility network

Vision: Electric-Automated-Connected-Public

Connected via WiFi, Cellular

Public and On-Demand



Automated incl. Infrastructure

Electric and Wirelessly Powered

Use Cases – Different Solutions Needed