Evaluating Commercial and Prototyped HEVs

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Outlines

- Characterization of commercially available and prototyped hybrid-electric vehicles
- Comparative analysis of fuel economy gains
- Breakdown analysis of key MPG gain elements
- Introduction of an alternative modeling approach: "*conventionalize*" commercial and prototyped HEVs
- Assessing incremental MPG benefits of each key step
- Conclusions
- Lessons learned and future direction

Commercial and Prototyped HEVs

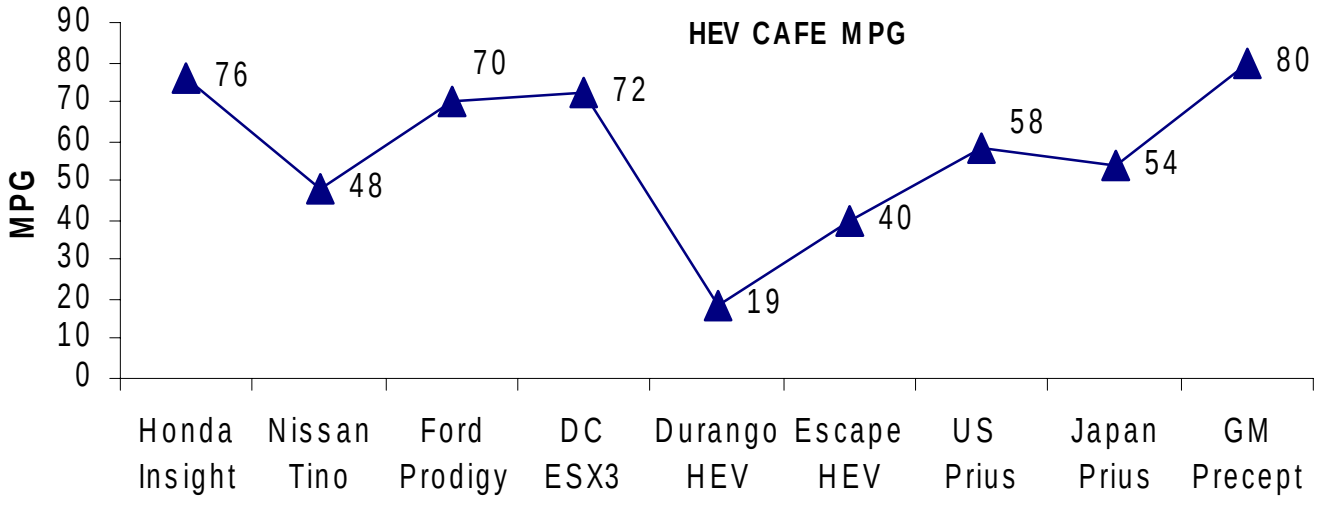
HEV Names	Type	Status	Curb wt.(lb.)	Power Plant	Engine Size (L)	Engine hp	Battery Type	Motor Peak kW	Transmission	CAFE MPG	MPG Sources	Z60 (Sec.)
Japan Prius	Gasoline Hybrid	Commercial	2,783	SI I-4	1.5	58	NiMH	30	CVT	54	EPA	14.1
US Prius	Gasoline Hybrid	Commercial	2,765	SI I-4	1.5	70	NiMH	33	CVT	58	EPA	12.1
Nissan Tino	Gasoline Hybrid	Commercial	3,300	SI I-4	1.8	100	Li-ion	17	CVT	48	Nissan	13.0
Honda Insight	Gasoline Hybrid	Commercial	1,760	SI I-3	1.0	67	NiMH	10	M5	76	EPA	10.6
Durango HEV	SUV Hybrid	Proto-typed	5,267	SI V6	3.9	175	PdA	66	A4	19	DC	9.1
Escape HEV	SUV Hybrid	Planned	3,582	SI I-4	2.0	130	?	52	?	40	Ford	9.0
Ford Prodigy	Diesel Hybrid	Proto-typed	2,387	CIDI I-4	1.2	74	NiMH	15	A5	70	PNGV & Ford	12.0
DC ESX3	Diesel Hybrid	Proto-typed	2,250	CIDI I-3	1.5	74	Li-ion	25	EMAT-6	72	PNGV & DC	11.0
GM Precept	Diesel Hybrid	Proto-typed	2,590	CIDI I-3	1.3	59	NiMH	35	A4	80	PNGV & GM	11.5

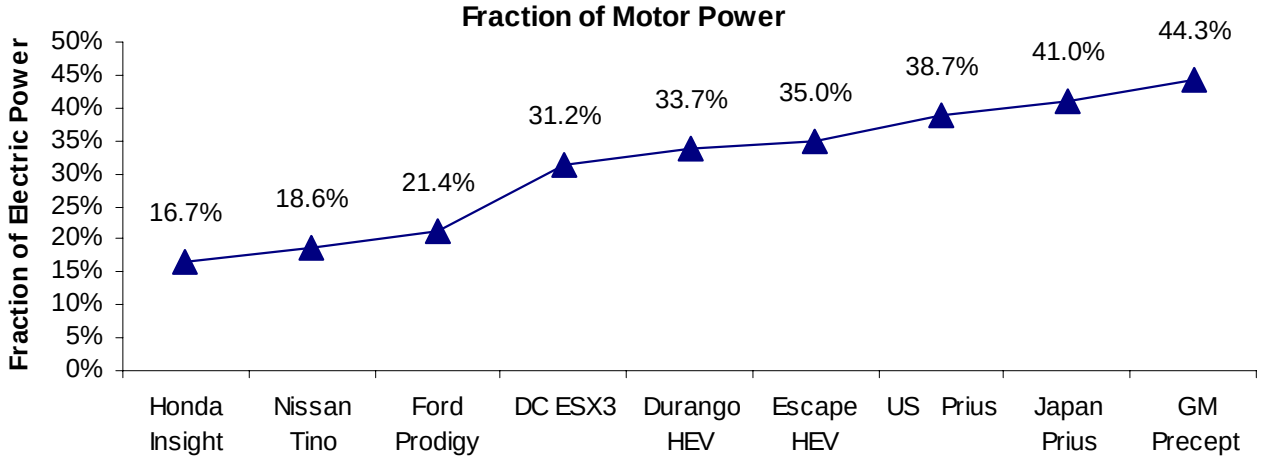
CAFE MPG represents combined EPA City and HWY MPG (or 55/45 MPG), all MPG figures use unadjusted certification values

Some other general features

- Common features:
  - Charge-sustaining, grid-independent
  - Power assist, load-following strategy
  - Zero or minimal pure electric range
  - Parallel- or near parallel (Prius) configured
- Differences
  - Different vehicle classes: compact cars, two seaters, large & small SUVs, and midsized cars.
  - Different development stages:
    - commercially available (gasoline HEVs),
    - production prototype (Durango),
    - commercially planned (Escape),
    - concept prototype (PNGV diesel HEVs)

MPG Values and Fraction of Electric Power of Selected HEVs

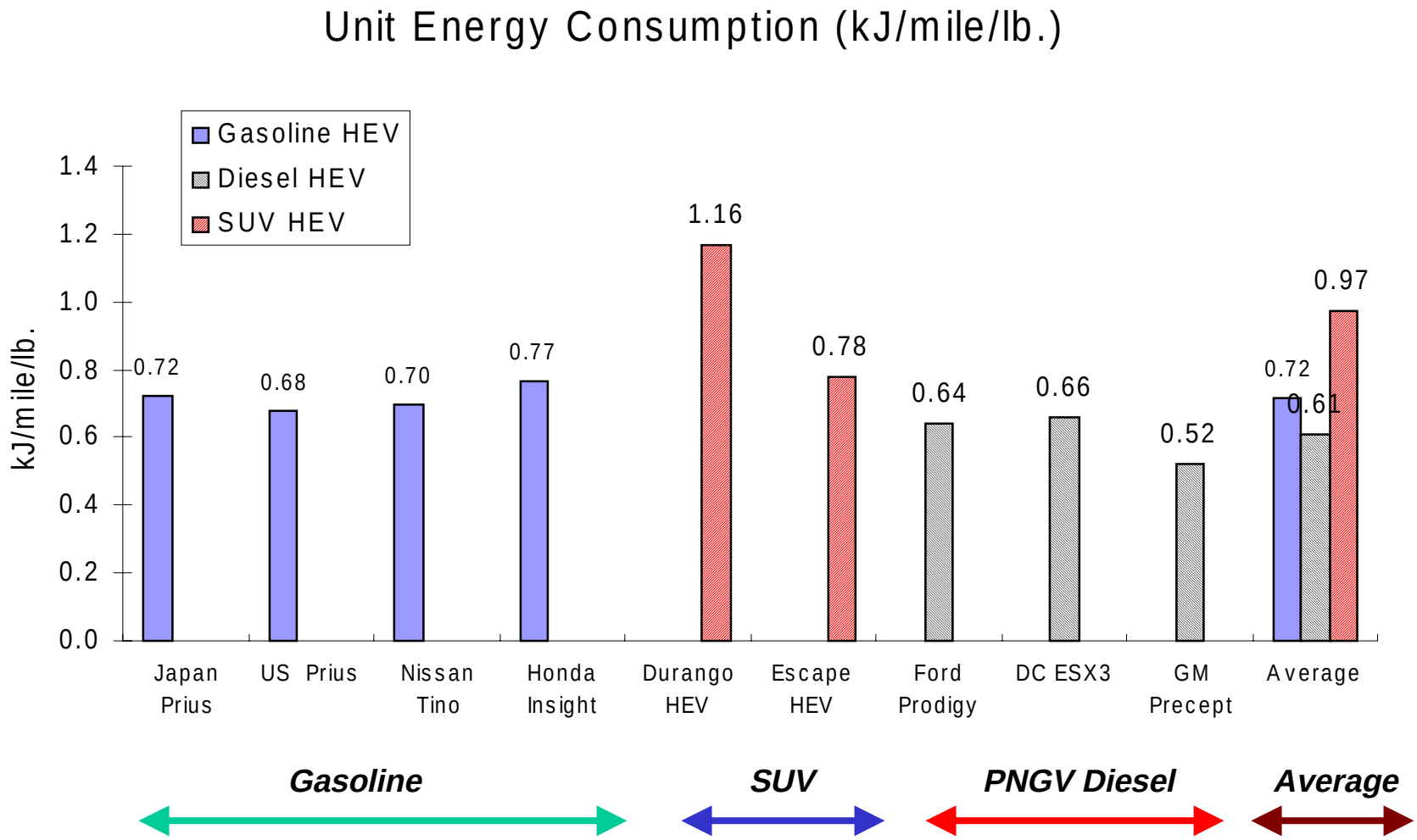




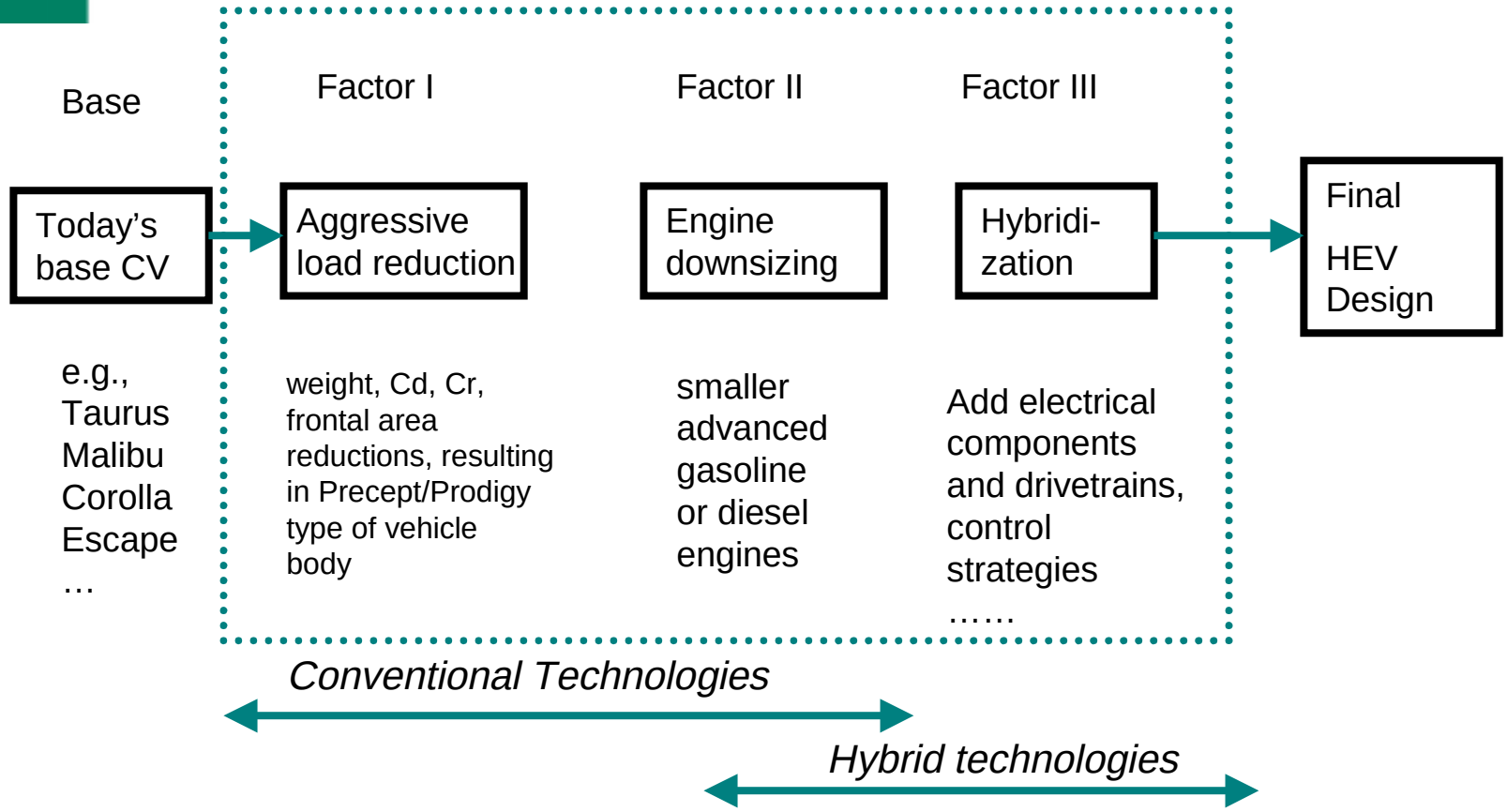
Mild Hybrid → Increasing electrical power fraction → Full Hybrid

HEV Unit Energy Consumption

(Energy efficiency per unit of vehicle weight)

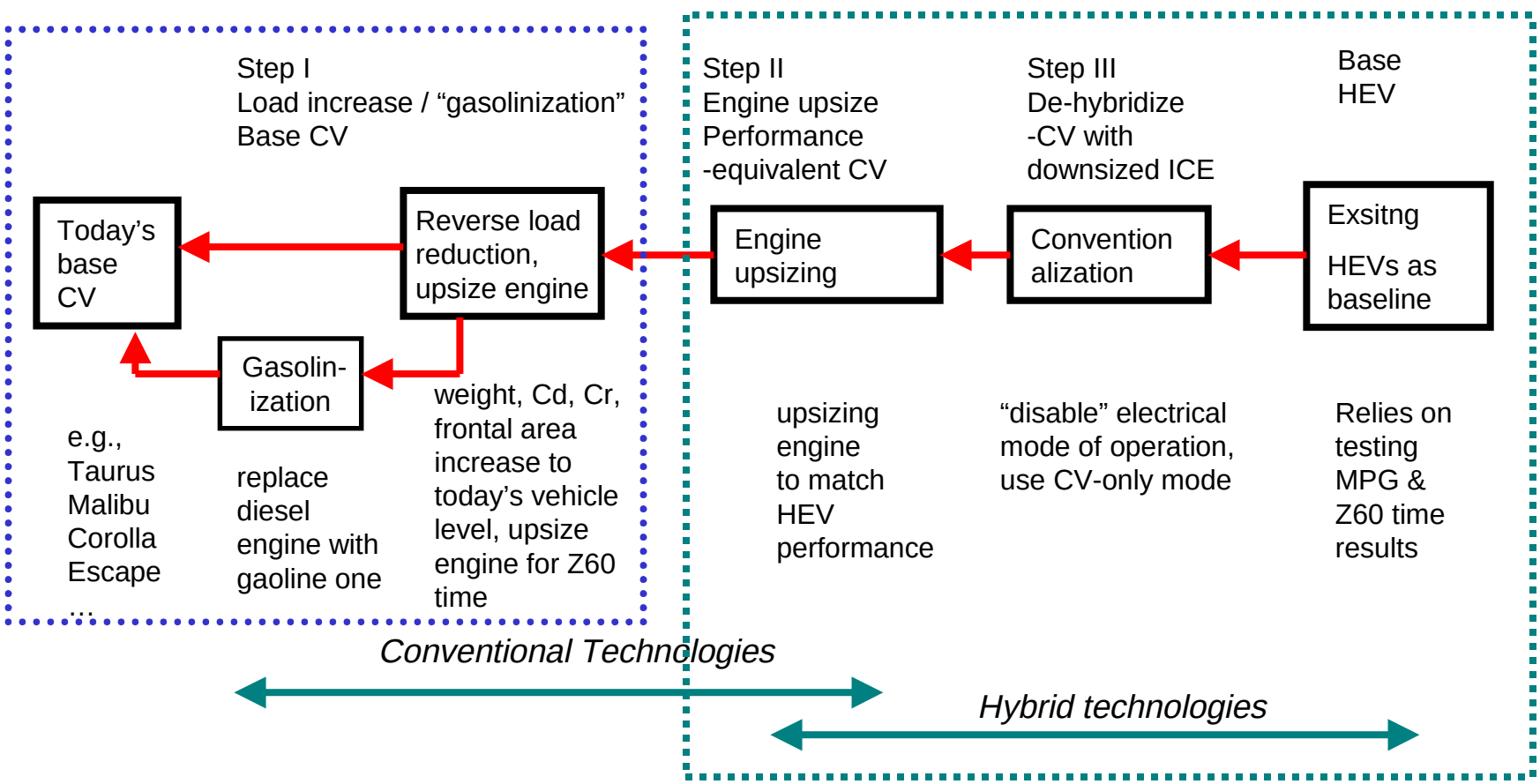


Methodological Elements of Hybridization
Three Key Factors :



To assess MPG gains associated with each element.
Key modeling challenge: Step III Hybridization – uncertainties in hybrid technologies and future projections

Alternative Analytical Sequence of Hybridization: Reverse Hybridization - Conventionalize Existing HEVs

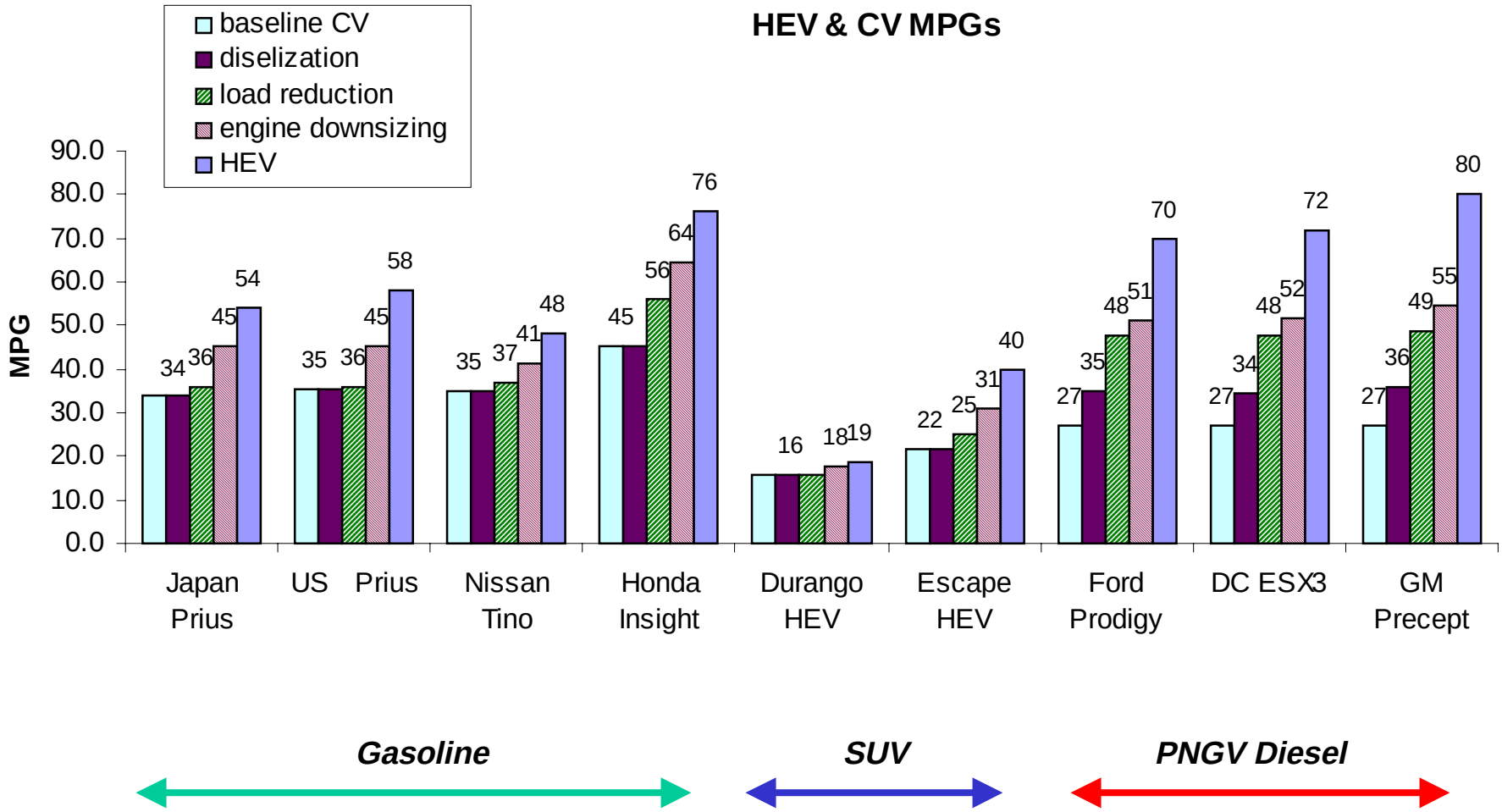


Modeling Advantages: Avoid uncertainties in hybrid technologies and future HEV projections

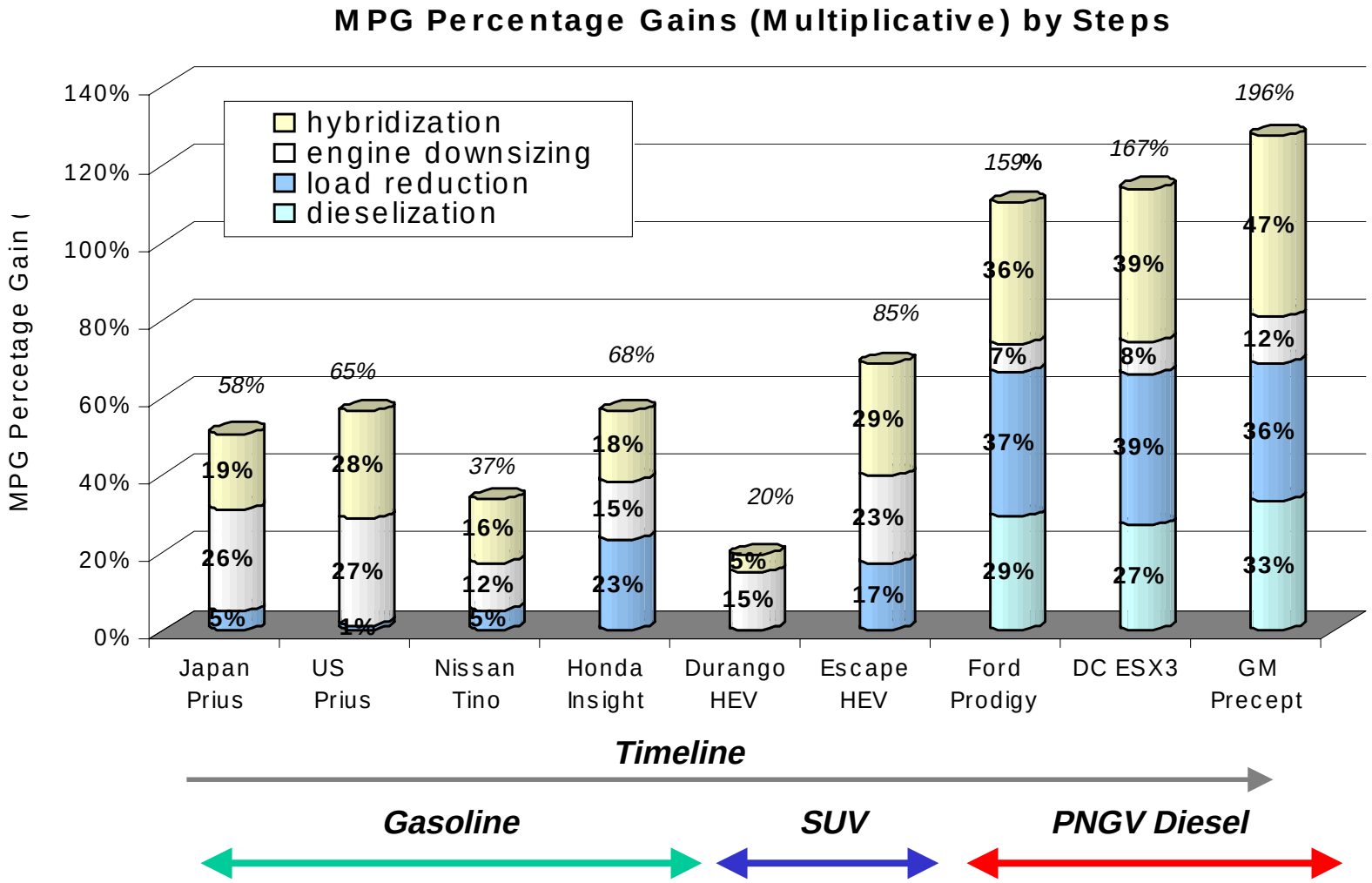
Modeling Methodology Highlights

- No need to model hybrid electric vehicles – use published MPG and 0-60 performance figures
- Use Modal Energy and Emissions Model (MEEM) for CV Modeling
- Rely on available engine maps and Information:
  - Atkinson engine (for Prius), VTEC engine (for Insight, Tino & Escape), VW 1.9 LTDI engine (for diesel hybrids), Explorer 4.0 L engine (for Durango)
- Engine Scaling routine for resizing on-board engines
- Estimate 0-60 performance for each step
- Construct CV-counterparts and base CVs on performance-equivalent basis
- Calculate performance-equivalent MPGs

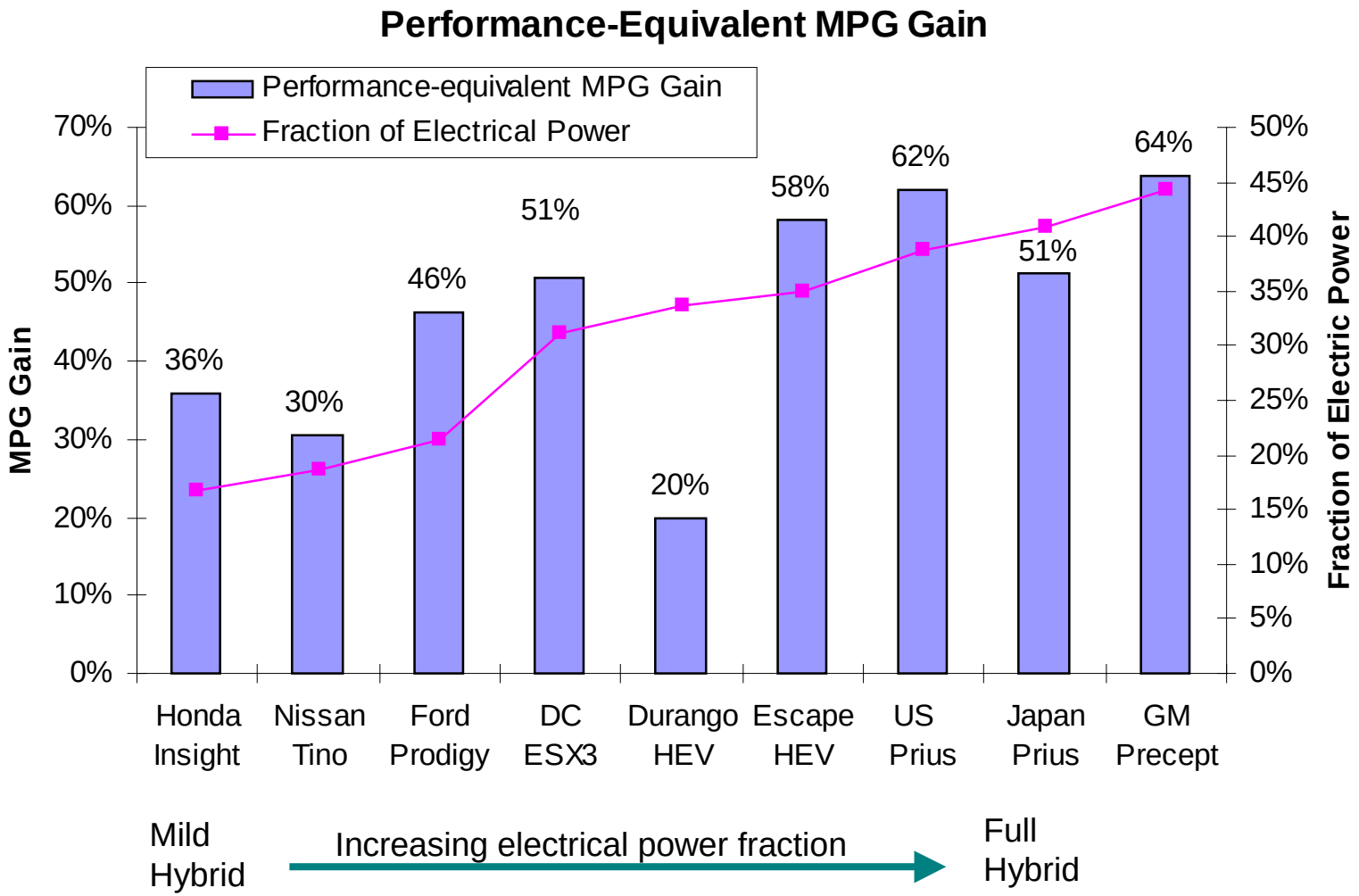
CAFE MPG (Gasoline-Equivalent) through steps of (Dieselization), Load Reduction, Engine Downsizing & Hybridization (All Steps I, II, & III)



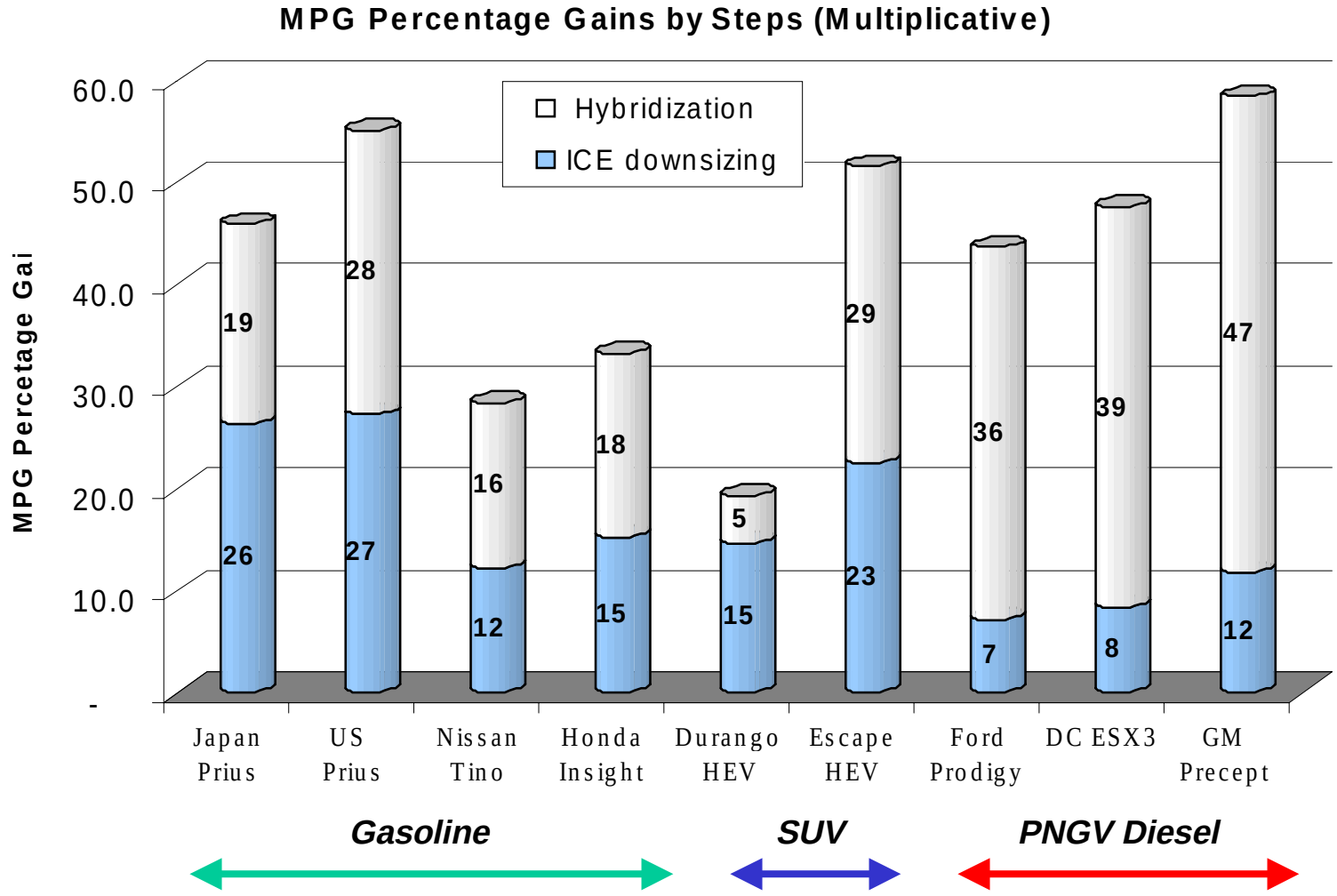
CAFE MPG (Gasoline-Equivalent) Gains from (Dieselization), Load Reduction, Engine Downsizing & Hybridization (All Steps I, II, & III, e.g., from Taurus to Prodigy)



Performance-equivalent CAFE MPG gains from engine downsizing and hybridization (Steps II & III, after load reduction measures, e.g., from "Prodigy CV" to Prodigy HEV)



CAFE MPG gains from engine downsizing and hybridization (II) (Steps II & III, After load reduction measures)



Conclusions

- Commercial and prototyped HEVs show wide variety of technological choices, configurations and development stages
- Fraction of on-board electric power varies greatly, from below 17% for Insight, to above 44% for Precept.
- Based on reported figures, the three PNGV diesel HEVs have the lowest unit energy consumption. In other words, they are most energy efficient in carrying vehicle load.
- The GM Precept has the most fuel efficient engineering design. The Durango HEV is the least efficient one.
- On average, I estimate that PNGV diesel HEVs achieve about 174% gain in MPG - In a multiplicative incremental fashion, I estimate about 30% gain from dieselization, 37% gain from load reduction, 9% gain from engine downsizing, and 41% gain from hybridization.
- On average, I estimate commercial gasoline HEVs achieve about 57% gain in MPG (on performance equivalent basis) - In a multiplicative fashion, I estimate about 9% gain from load reduction, 20% gain from engine downsizing, and 20% gain from hybridization.
- Comparing with commercial gasoline HEVs, my estimates imply that PNGV diesel HEVs get far better benefit from hybridization, but far less from engine downsizing.
- The planned Escape HEV appears to have similar unit energy efficiency as the gasoline hybrid cars. But to achieve 40 MPG goal, it requires more aggressive load reduction measures and similar use of hybrid technologies of commercial hybrid cars

Future of HEV Development

- Technologies are available to achieve high fuel efficiency gains
- Emerging modeling tools can help better understand technology options
  - Effectively assess incremental MPG benefits associated with each technology
  - Address trade-offs among technology choices
  - Establish technology choices and cost model
  - PSAT, ADVISOR and HEVCOST
- Cost-effectiveness in guiding technology choices
  - Assess cost-effectiveness of incremental MPG gains
  - Prioritize technology menu based on cost-effectiveness
  - Set MPG and cost target
  - Choose technologies based on priority menu with MPG/cost constraints