Exploratory Decision Analysis of the Future of the Automobile in the USA

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with

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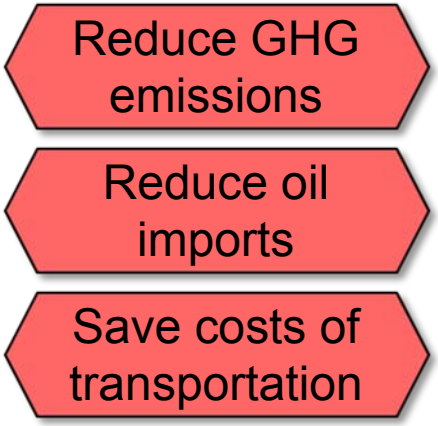
Costa Samaras, RAND, Cary Bloyd, PNL

DAAG, Houston, Texas, April 20-21, 2011

The Automobile in the USA

- Transportation consumes 28% of energy, 30% of GHG emissions. Most oil is imported.
- How can we?



- Biofuels, electric vehicles, hydrogen fuel cells, CNG, or just improve ICE efficiency?
- Obama's plan to reduce oil imports by one third over the next decade.
- Fleet turnover ~12 years

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Overview

- Open-source policy modeling
  - What is it and why?
- Exploratory decision analysis
  - ATEAM: Analytica Transportation Energy Assessment Model

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Elements of a decision analysis

Public policy decisions

- Renewable Fuel Standard
- Low Carbon Fuel Standard
- CAFÉ: Fleet efficiency
- Tax credits & incentives by technology
- Biofuel credits and tariffs
- Carbon tax
- RD&D

Consumer decisions

- Vehicle miles travelled
- Choice of fuel & technology
- Vehicle size

Industry decisions

- Products and pricing
- RD&D

Uncertainties

- Oil price
- Biofuels cost
- Battery cost
- ICE efficiency
- Light weighting
- GDP growth
- Consumer preferences

Objectives

- Reduce GHG emissions
- Reduce oil imports
- Save costs of transportation

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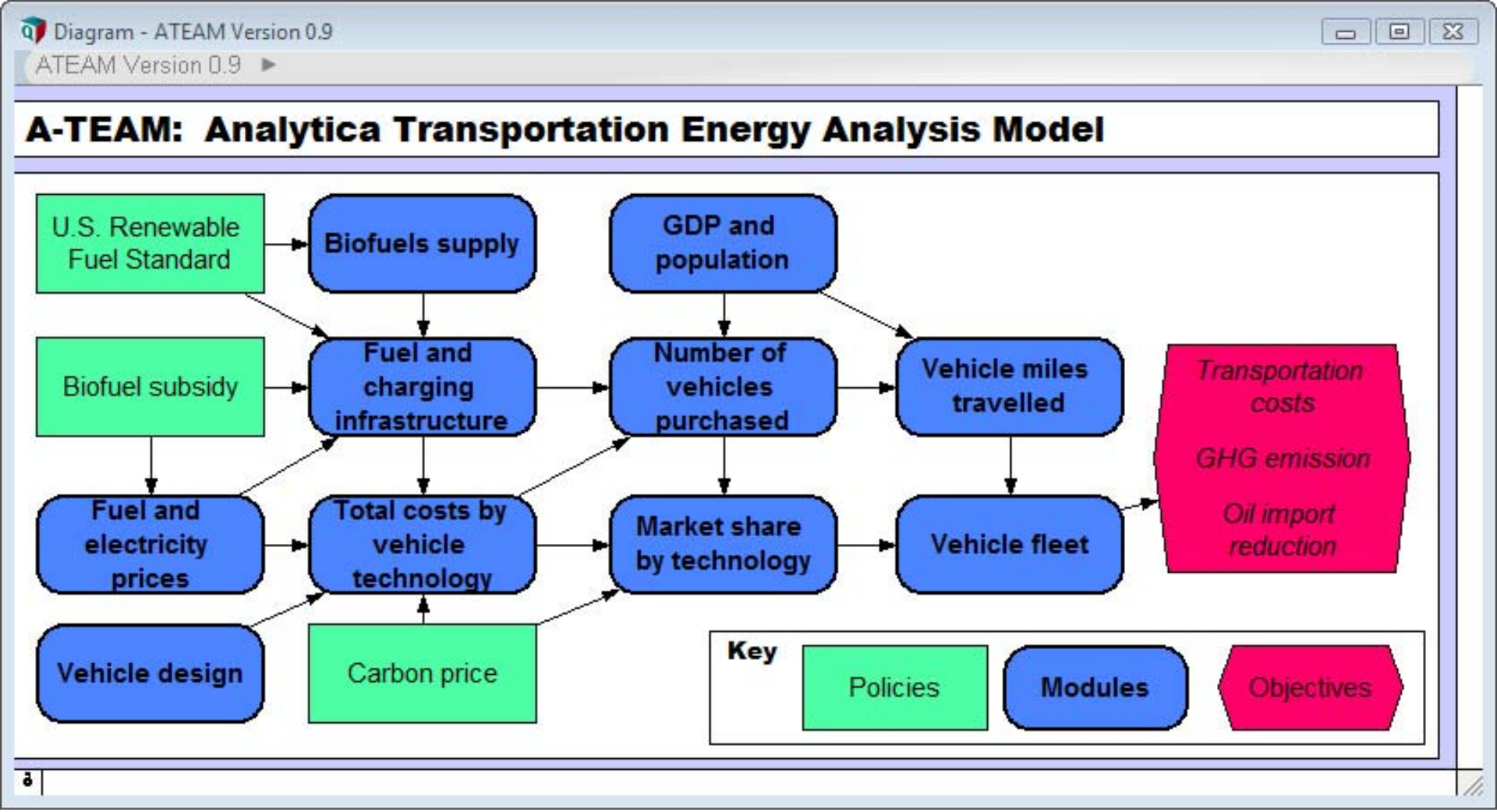

- To evaluate the effects of new fuels and technologies, including biofuels, CNG,, HEVs, PHEVs, HFCVs, on the US light-duty vehicle fleet costs, GHG emissions, and oil & gas imports.
- National, regional, state: to 2050

- Designed to be transparent and agile for fast exploration of scenarios, sensitivity and uncertainty analysis
- An open-source model built in Analytica by Lumina for PNNL, DoE Vehicle Technology Program, and others….

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ATEAM compares, combines, and extends existing studies and models

- **EIA's Annual Energy Outlook:** Uses AEO projections as baselines for comparison
- **Federal Policies**: E.g.
  - **RFS**: Renewable Fuel Standard
  - **CAFE**: Corporate Average Fuel Economy: Apr 1, 2010
- **NAS/NRC:** Compare scenarios on fuel economy, market penetration from recent studies by National Academy of Science
- **DoE/OBP:** Recent projections of biofuels production through 2015 and technology performance to 2050
- **DOE/VTP:** Recent projections of battery and other vehicle technology costs
- **VISION:** Spreadsheet model of US vehicle fleet (ANL)
- **GREET**: GHG emissions and fuel economy estimates from spreadsheet model (ANL)
- **Polysis**: ORNL and U Tn model of biomass production by county
- **EERE Risk Working Group and SEDS**: Probability distributions from expert elicitations for technology performance used in SEDS (Stochastic Energy Deployment System) (NREL)
- **Simple physics energy model** (SPEM) of energy use by vehicles, regression fit to EPA vehicle performance data (Sovran & Blaser, Lumina)

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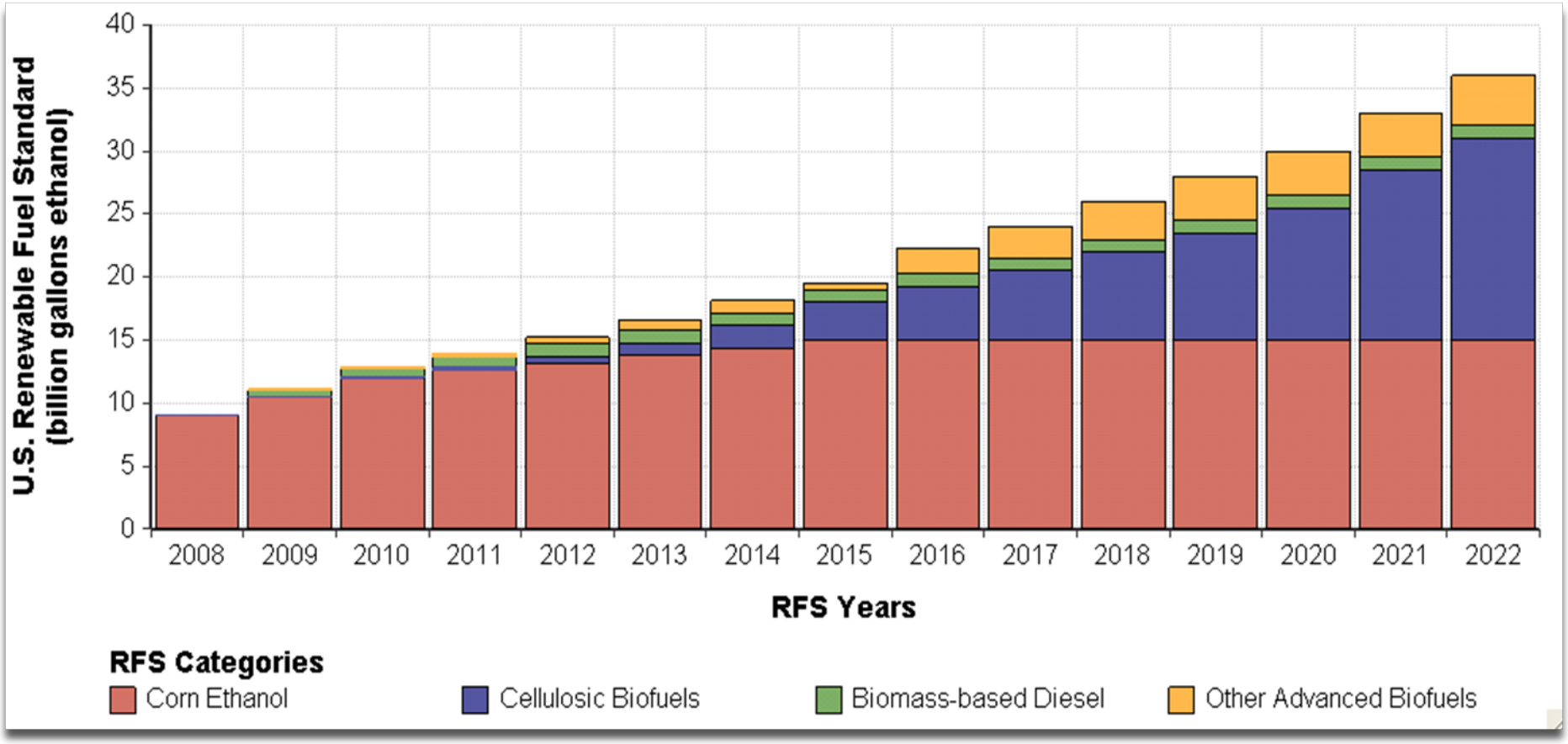
Renewable Fuel Standard

Renewable Fuel Standard (RFS2)



- Created under Energy Policy Act of 2005
- Amended under Energy Independence and Security Act (EISA) of 2007

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How can we consume that amount of ethanol?

Q1. How many FFVs do we need to sell to absorb the biofuels required by RFS2?

• 90% gasoline

• 85% ethanol
• 15% gasoline

Conventional Vehicle MY 2001 and

Ethanol Demand f
E10 to hit "blend wa

EPA allows us
E15 as
intermediate ble

Q2. How does it help to introduce E15 as an intermediate blend?

Sources: Moriarty (NREL), 2010
AEO, 2010

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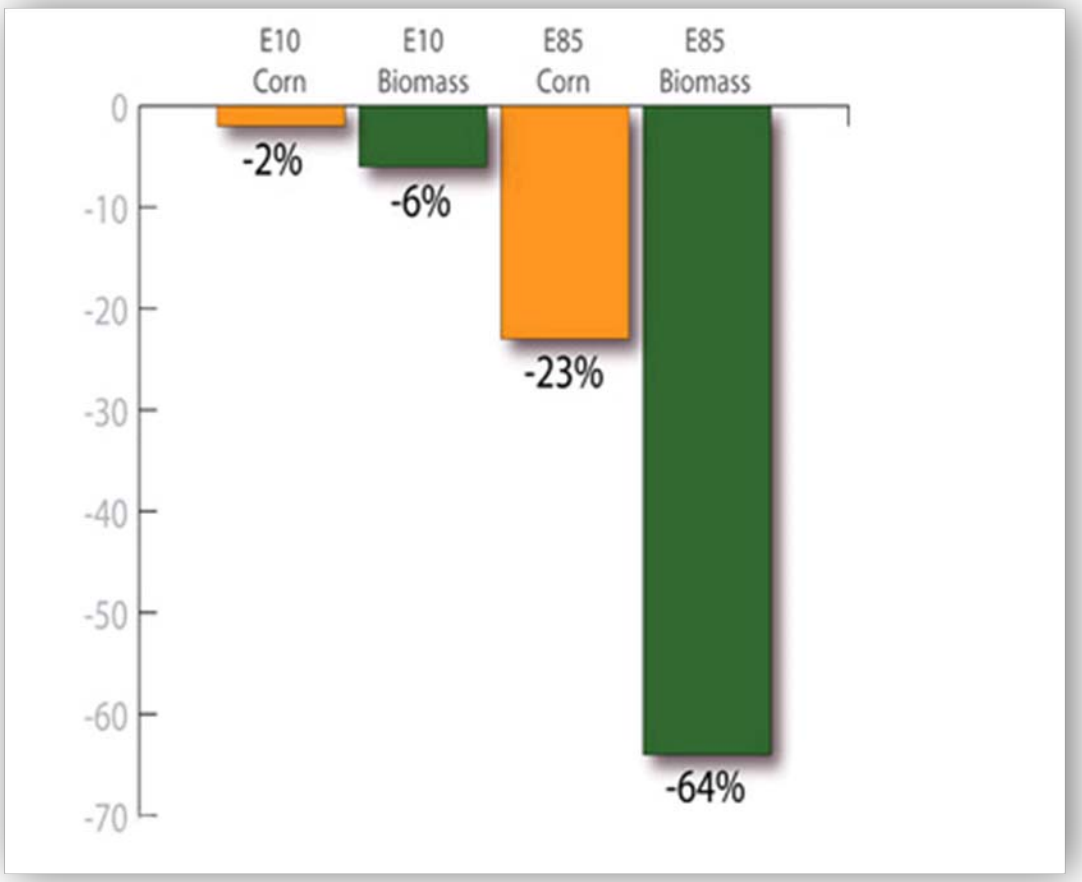
Percent reduction in GHG emissions per mile from ethanol blends and sources



- E85 achieves greater emission reductions than E10
- Cellulosic ethanol achieves greater emission reductions than does corn ethanol

Source: Wang (ANL), 2005

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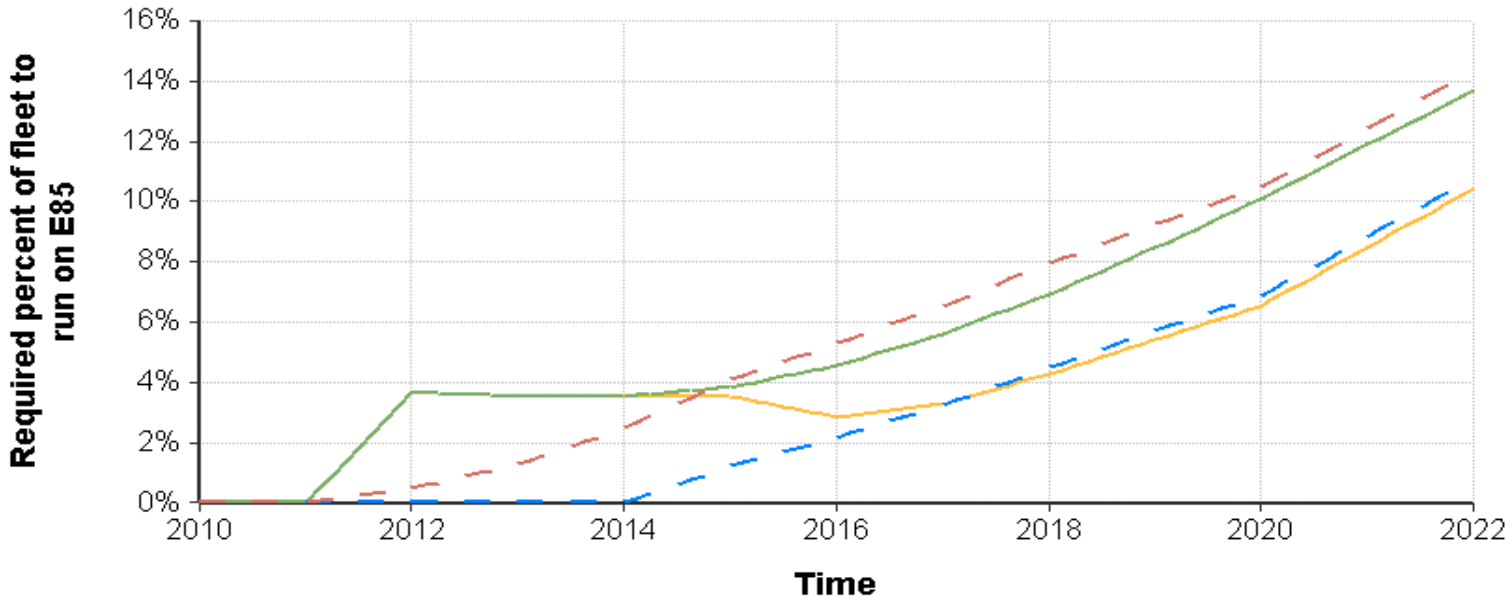
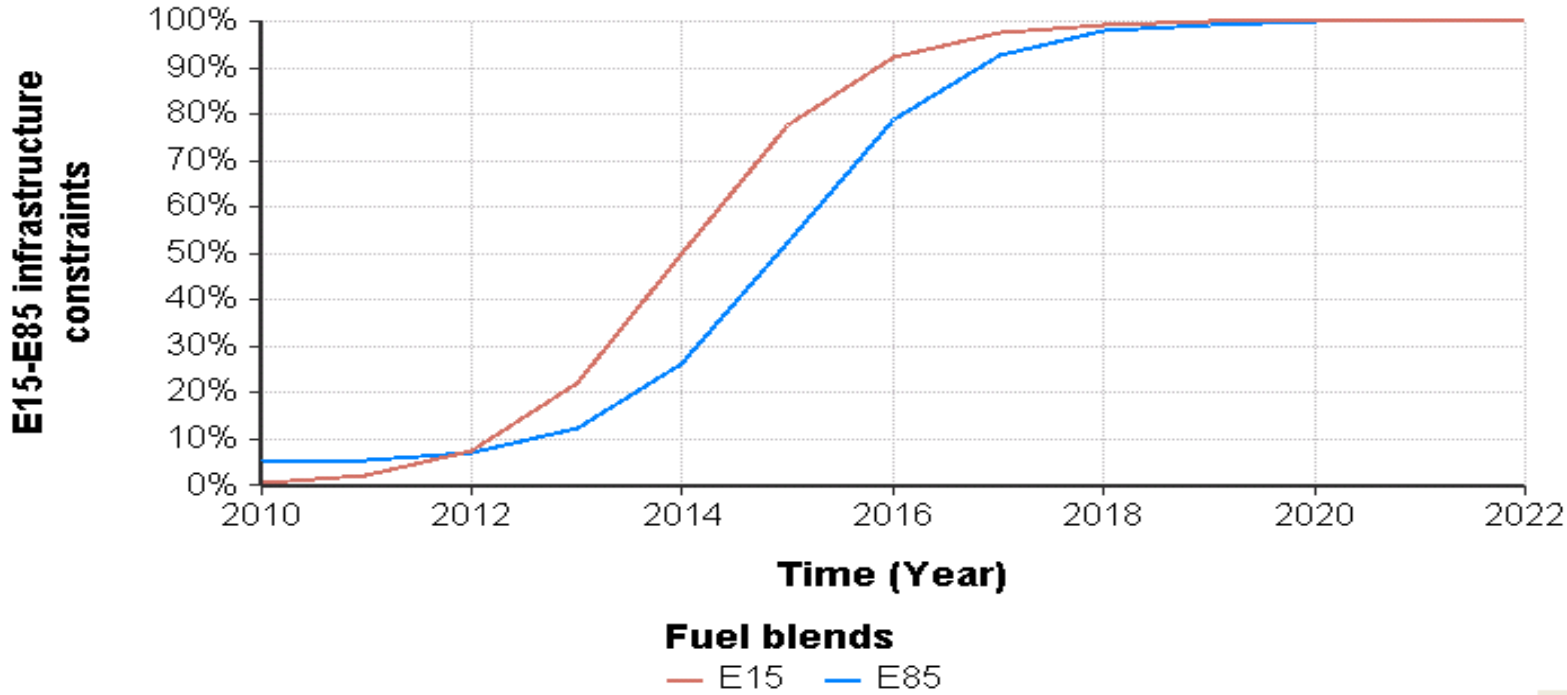
What percent of light-duty vehicles must run on E85 full-time to consume biofuels required by RFS?





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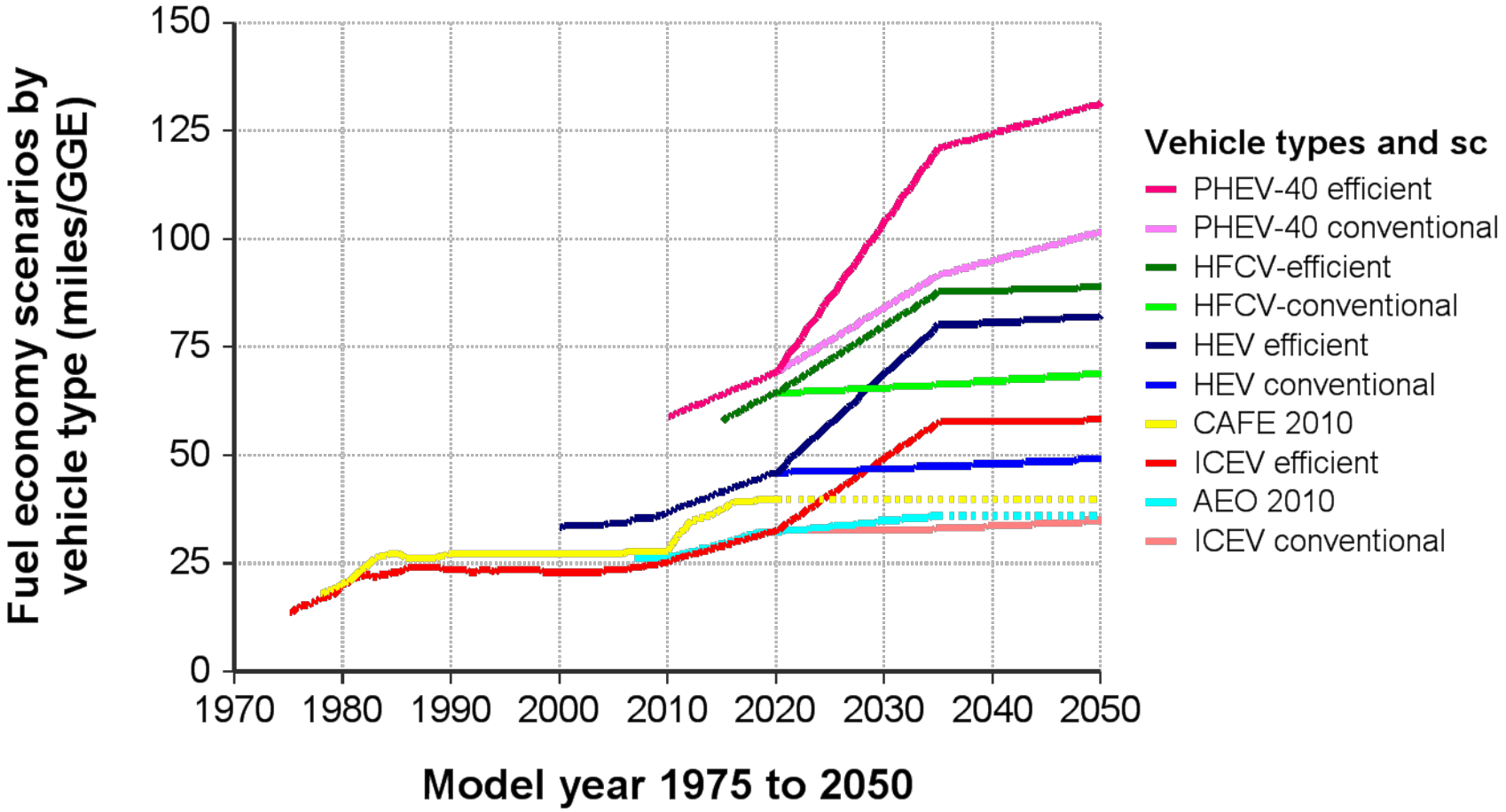
Fuel efficiency

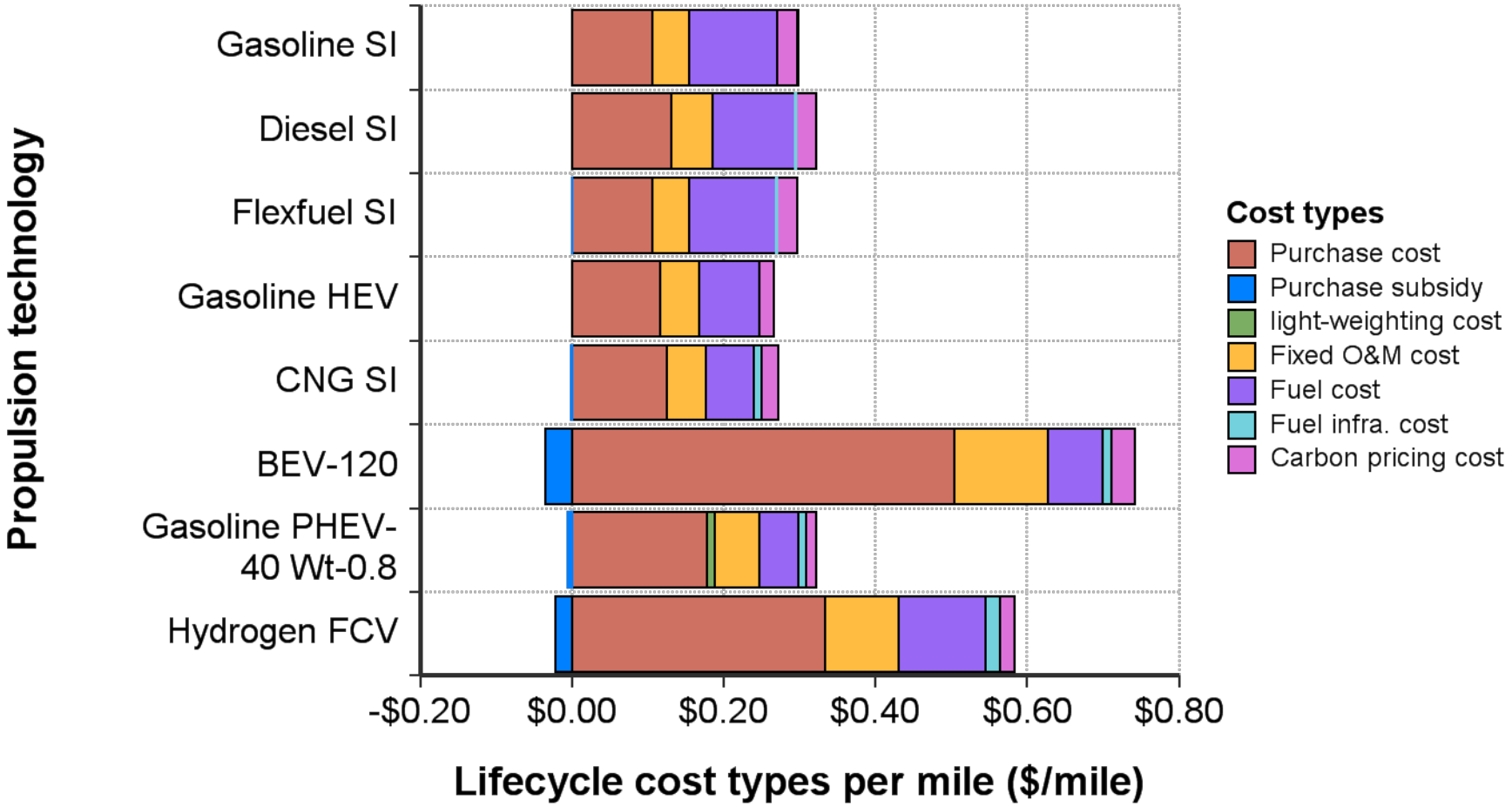
Fuel efficiency Scenarios



- Fuel economy for CAFE, AEO and by vehicle type based on NAS scenarios
- Assessment of weight impacts on fuel economy

Comparing propulsion technologies by levelized cost per mile in 2012

Levelized cost/mile



- SI - spark Ignition; HEV - hybrid electric vehicle; CNG - compressed natural gas; BEV - battery electrical vehicle; PHEV - plug-in hybrid vehicle; FCV – Hydrogen fuel cell vehicle

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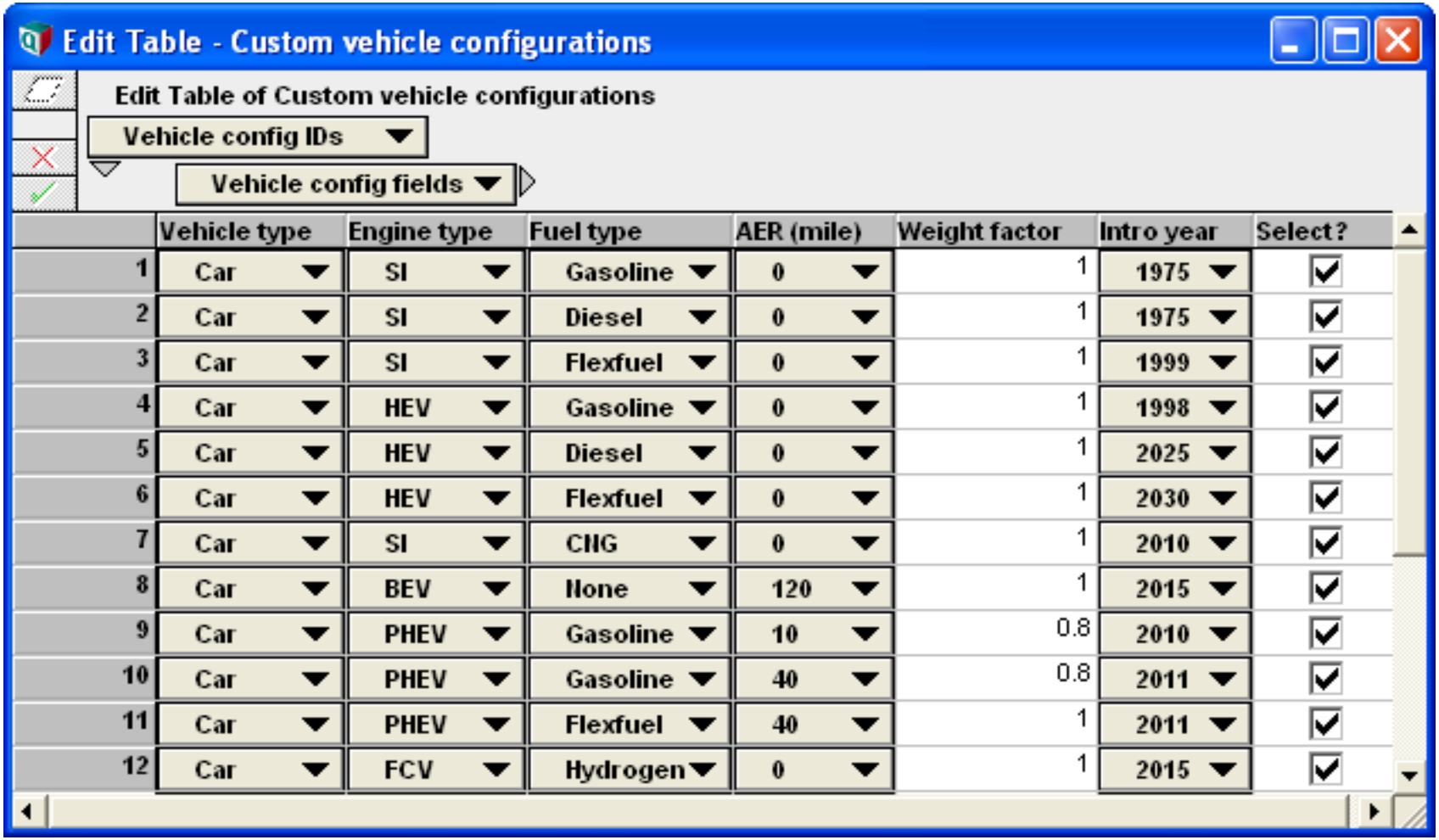
Vehicle design

Select and configure vehicles



	Vehicle type	Engine type	Fuel type	AER (mile)	Weight factor	Intro year	Select?
1	Car	SI	Gasoline	0	1	1975	☑
2	Car	SI	Diesel	0	1	1975	☑
3	Car	SI	Flexfuel	0	1	1999	☑
4	Car	HEV	Gasoline	0	1	1998	☑
5	Car	HEV	Diesel	0	1	2025	☑
6	Car	HEV	Flexfuel	0	1	2030	☑
7	Car	SI	CNG	0	1	2010	☑
8	Car	BEV	None	120	1	2015	☑
9	Car	PHEV	Gasoline	10	0.8	2010	☑
10	Car	PHEV	Gasoline	40	0.8	2011	☑
11	Car	PHEV	Flexfuel	40	1	2011	☑
12	Car	FCV	Hydrogen	0	1	2015	☑

Vehicle Fleet Scenarios

- You can define vehicle fleet scenarios and sets of vehicle technology and fuel combinations to compete in the market, such as:
  - **AEO Ref:** US DoE Annual Energy Outlook 2010 Reference Scenario: All vehicle techologies including ICEV, Flexfuel, HEV, BEV, PHEV and HFCV
  - **ATEAM Endogenous:** The same set of technologies, projecting market share by year based on levelized cost per mile, adjusted for preference and fuel availability.
  - **NAS Ref:** National Academy of Sciences reference: The types of vehicles considered in this case include conventional ICEV, and conventional HEV. AEO fuel economy to 2035 with linear extrapolation post 2035.
  - **NAS Hydrogen:** NAS Ref plus optimistic assumptions on hydrogen fuel cell vehicles.
  - **NAS PHEV:** NAS Ref plus plug-in hybrid vehicles.

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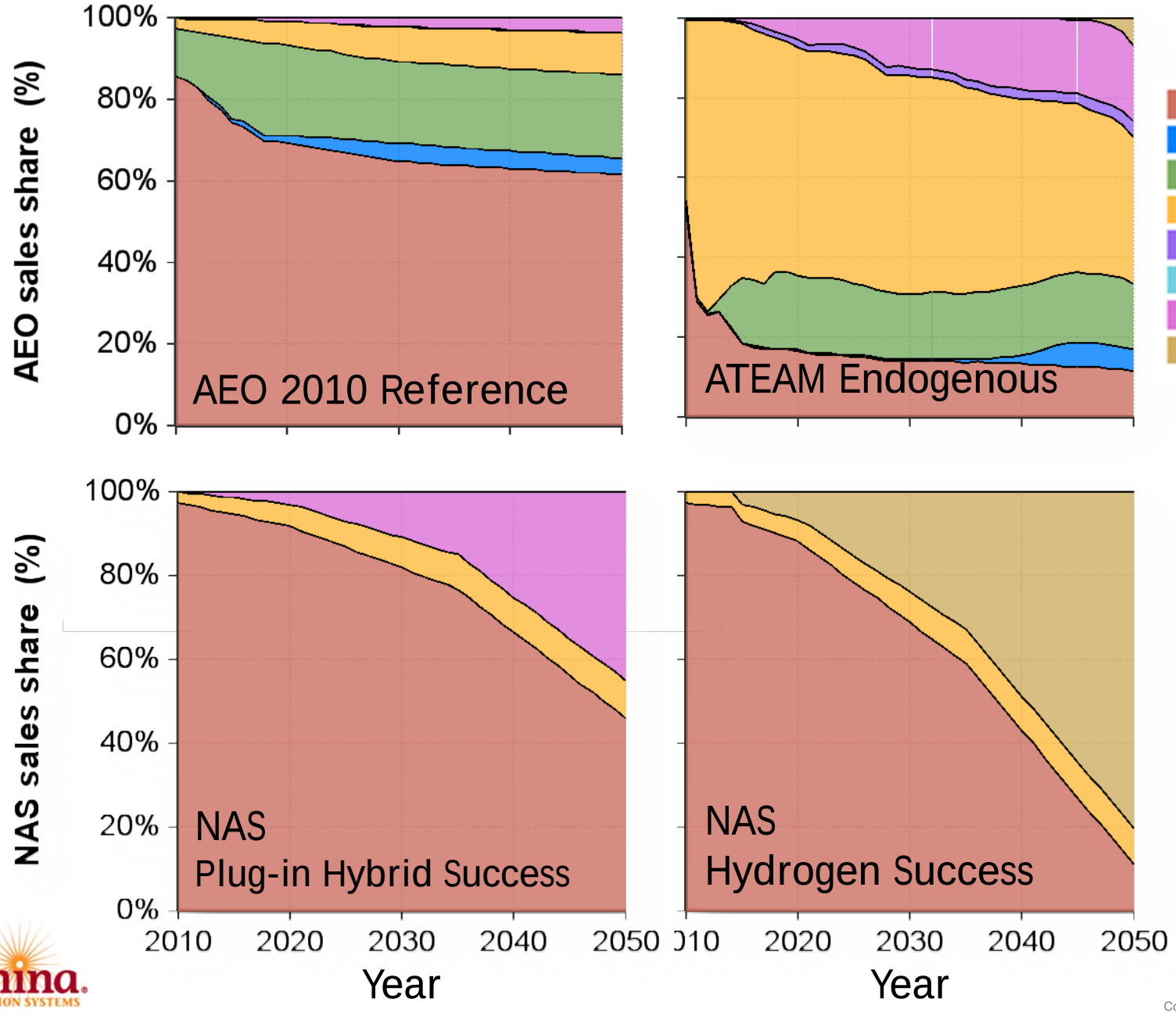
Scenarios for Market Share of Sales by technology



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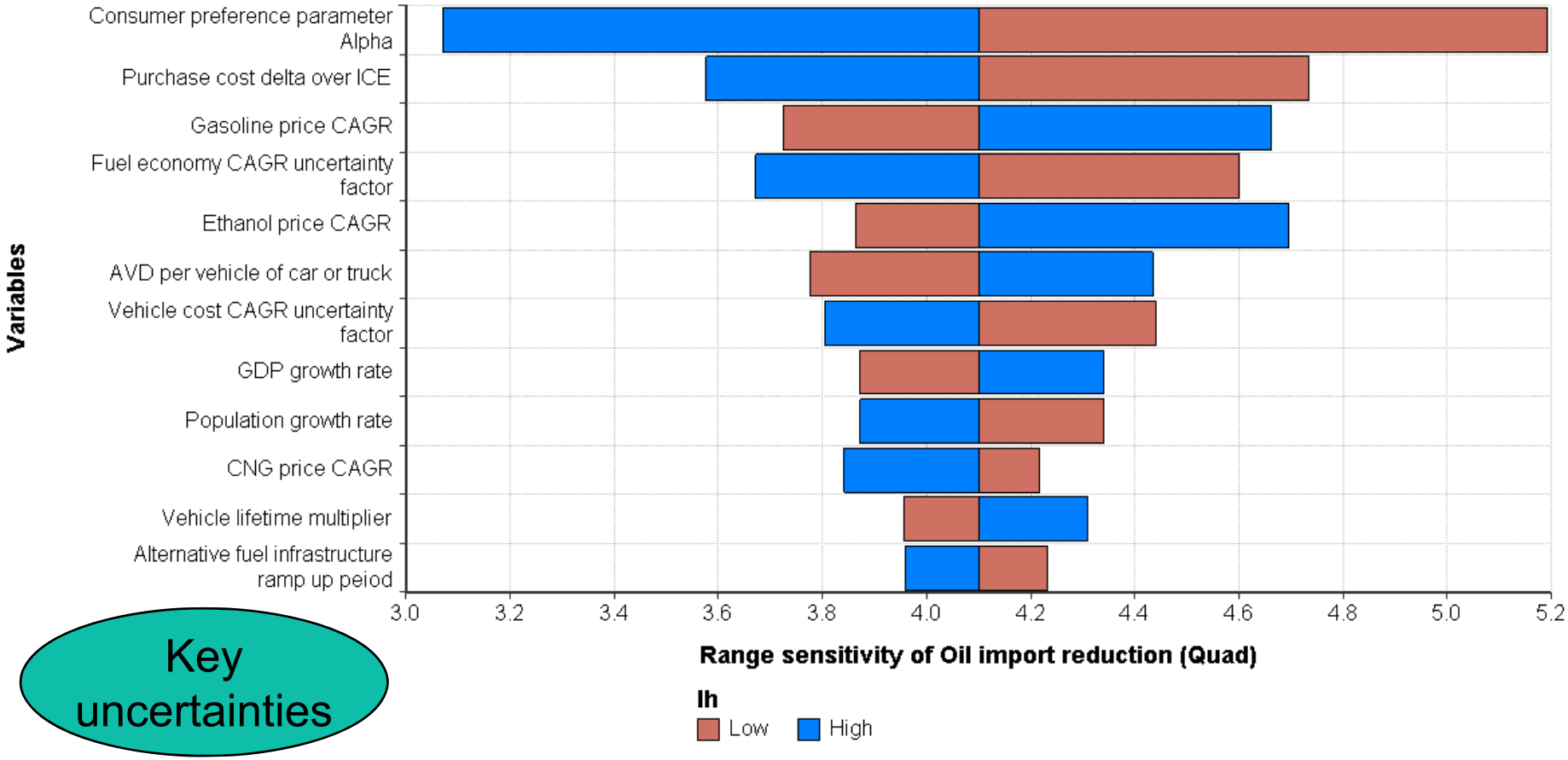
Reduce Oil Imports

Range sensitivity analysis: Effects on reduction in oil imports



Key uncertainties

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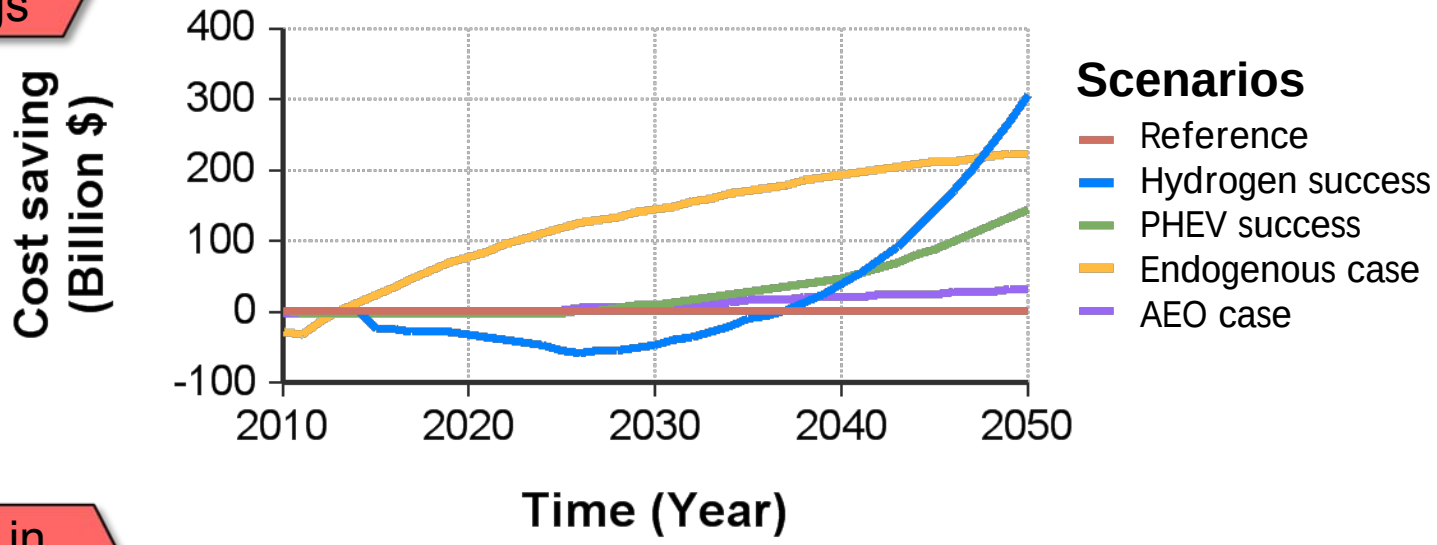
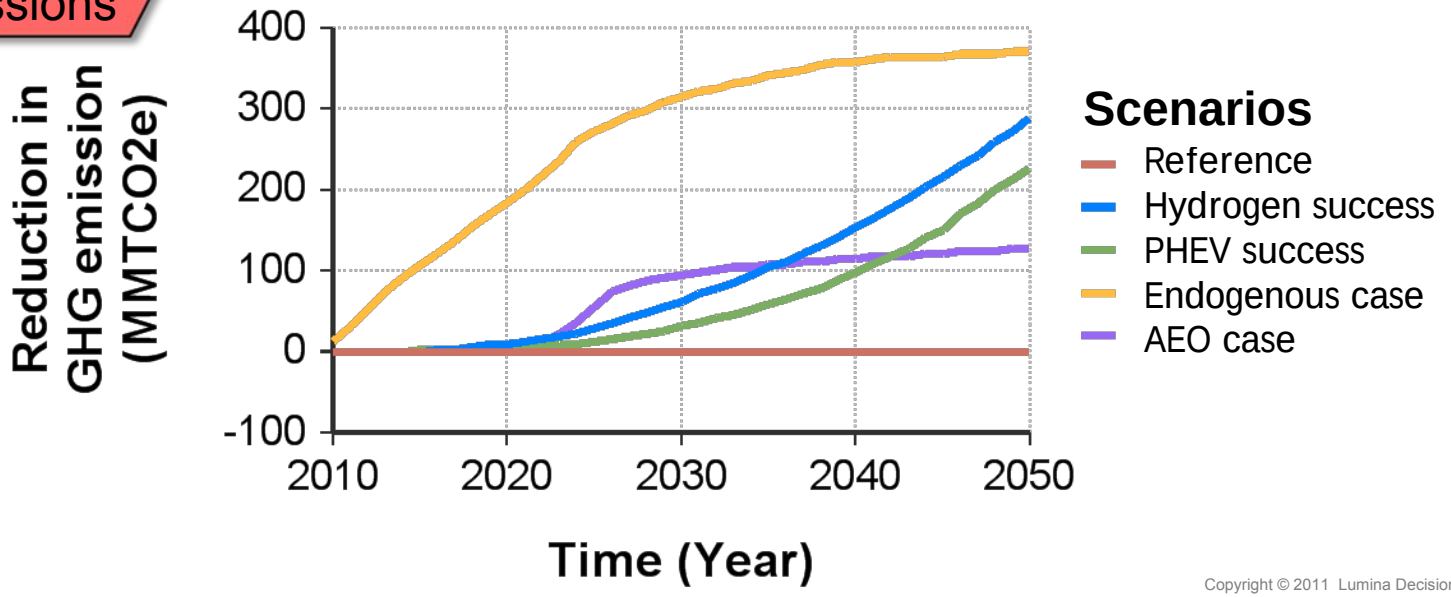
Economic and Environment Analysis

Transportation cost savings



Reduction in GHG emissions



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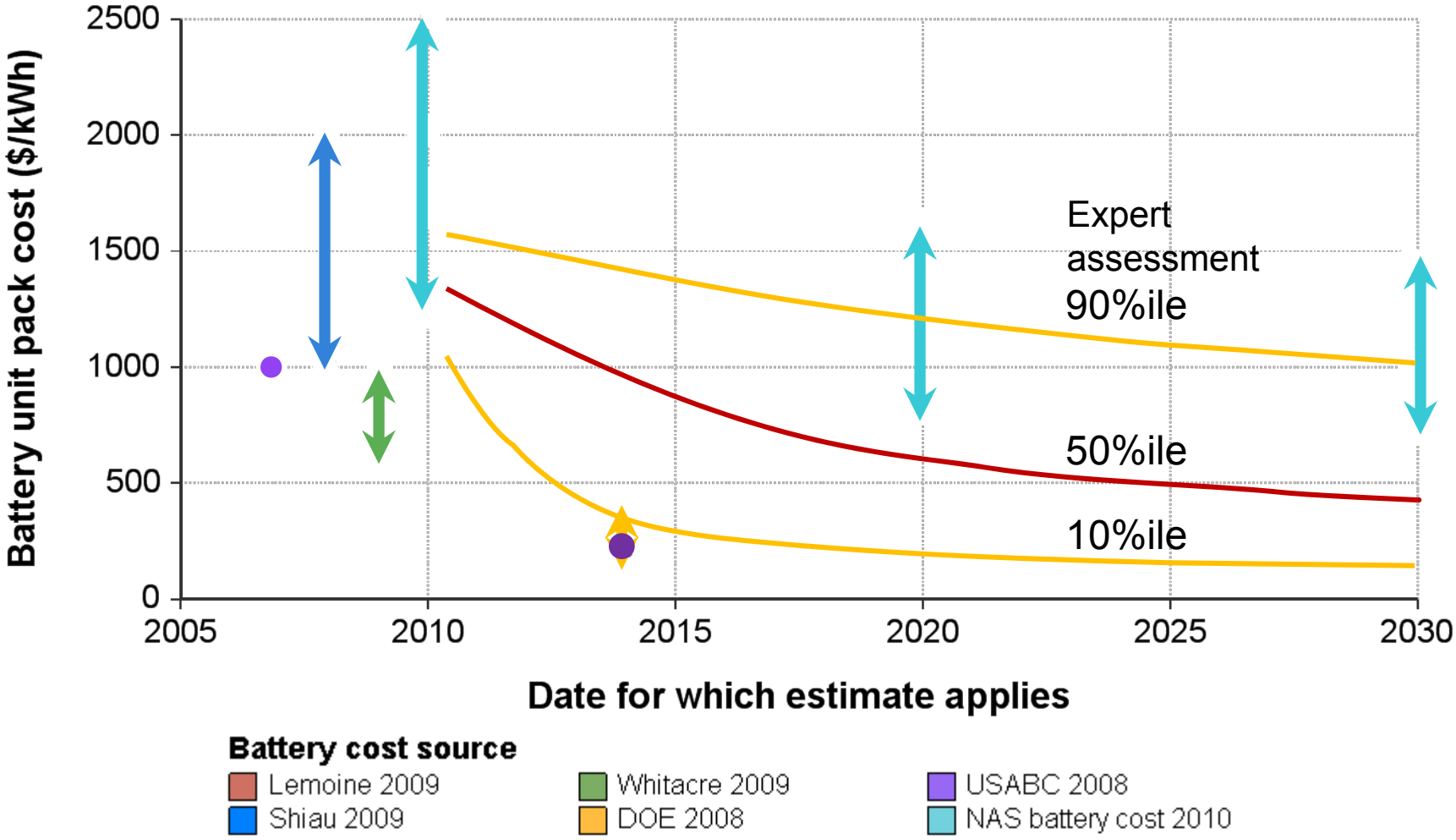
Battery costs

Li-ion batteries: Estimates of unit cost ($/kWh)



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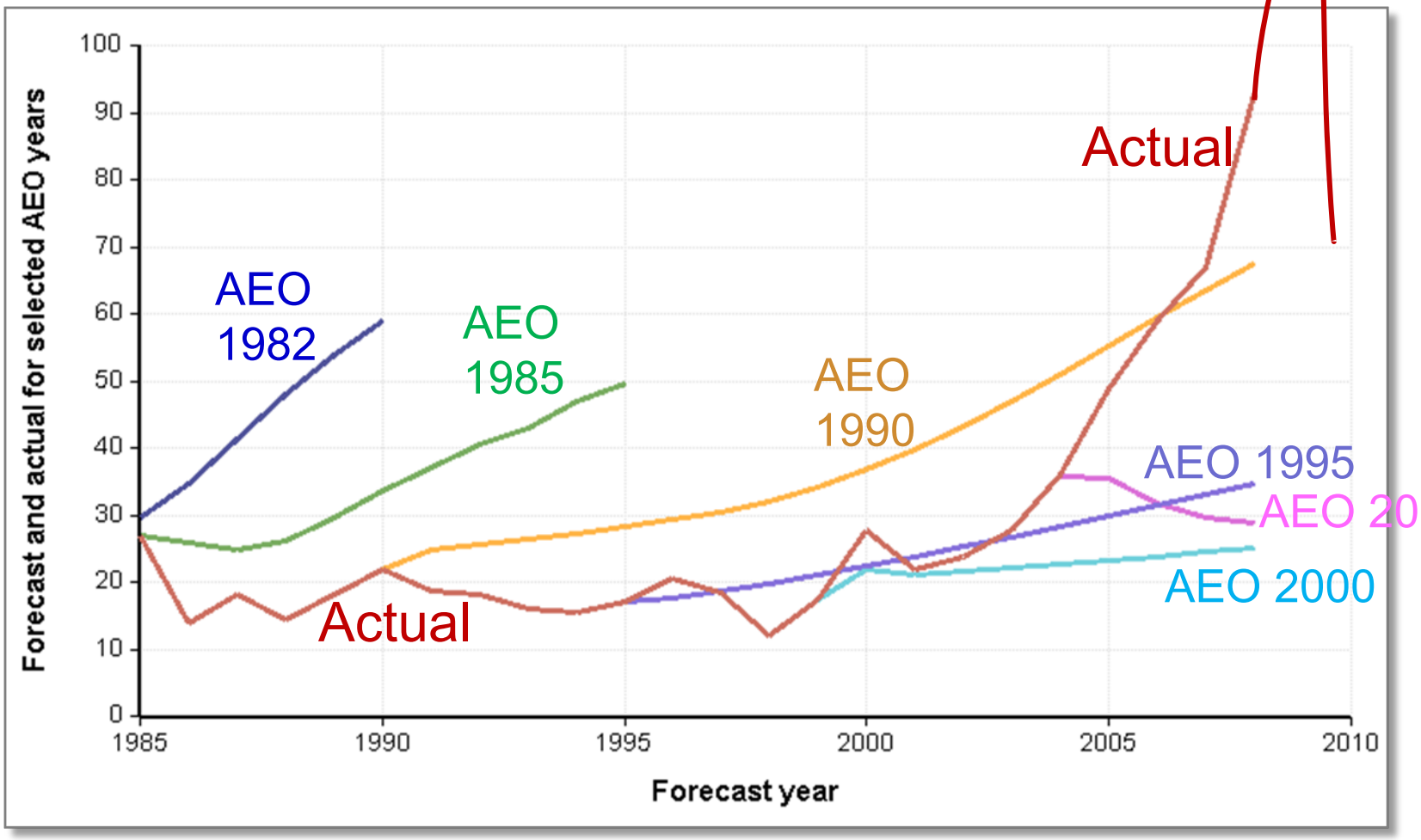
Retrospection on past AEO forecasts:

World oil price ($/barrel)

Oil price



Data from Annual Energy Outlook: Retrospective Review 2009.

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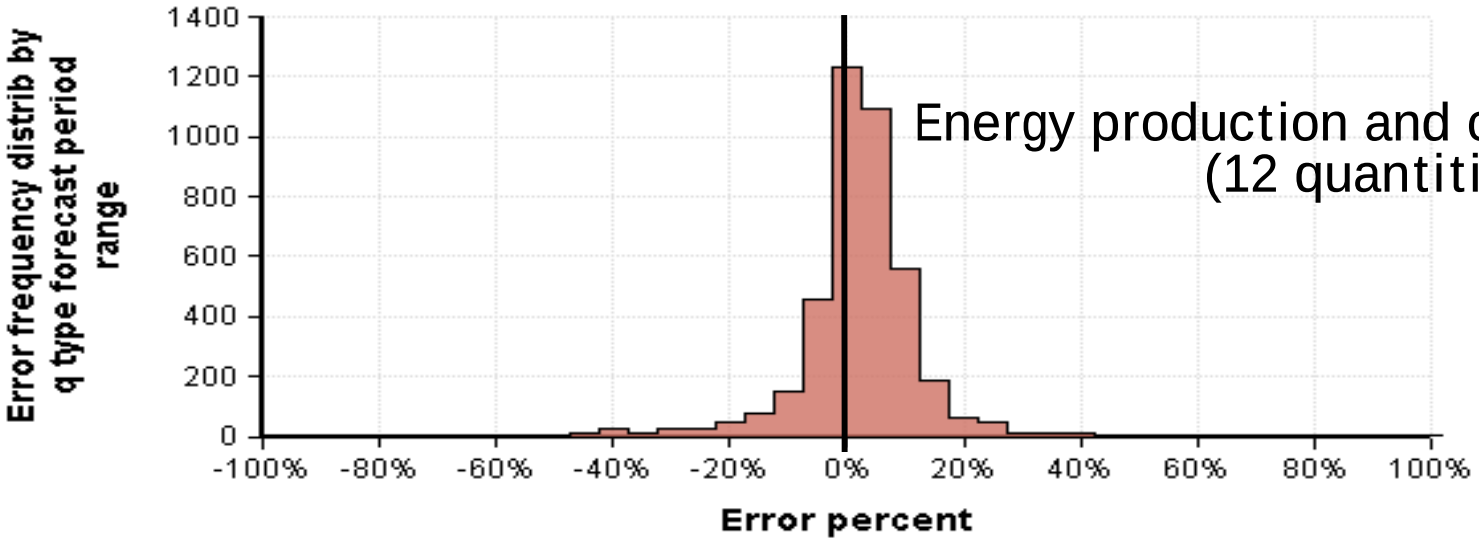
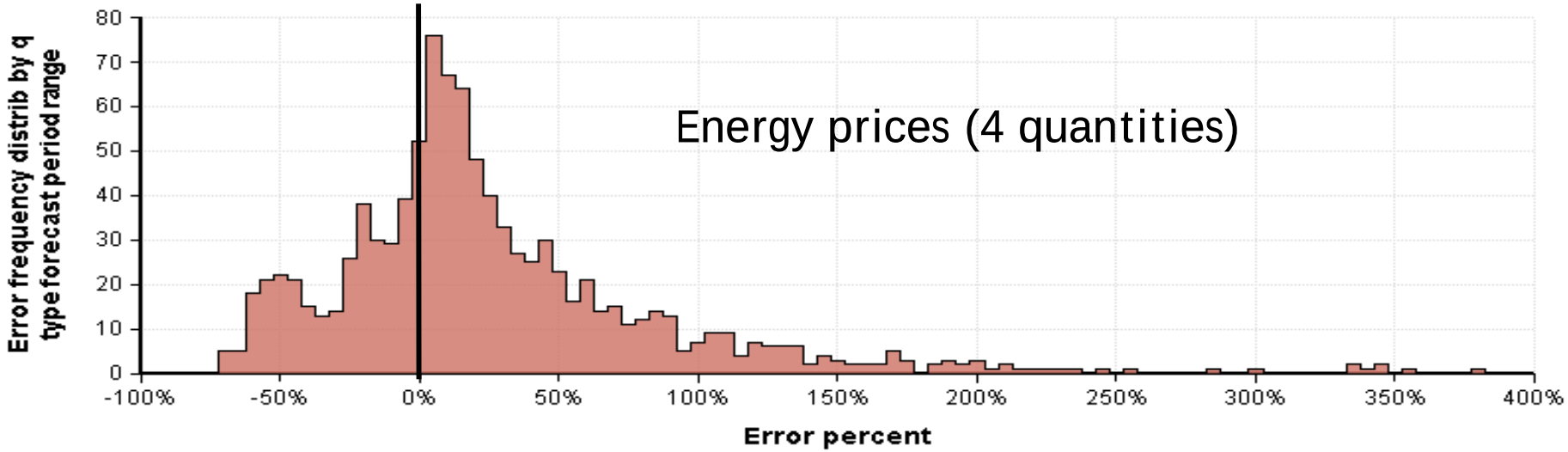
Distributions for percent error in AEO Forecasts 1980 to 2008





Data from Annual Energy Outlook: Retrospective Review 2009.

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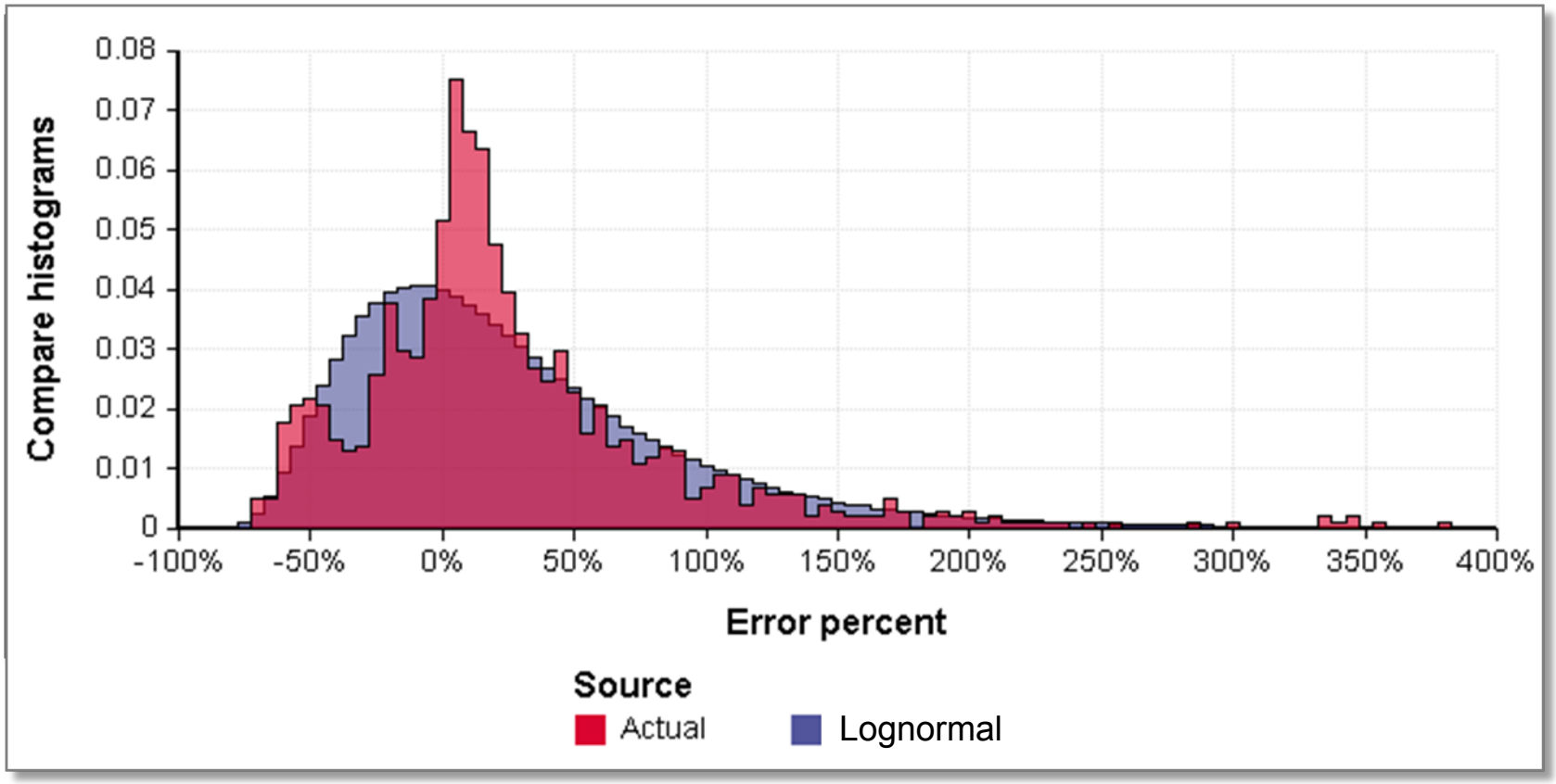
Fitting the empirical error distribution

for AEO energy price forecasts



	Quantity	Price
Geometric mean	1.001	1.118
Geometric st dev	1.087	1.638

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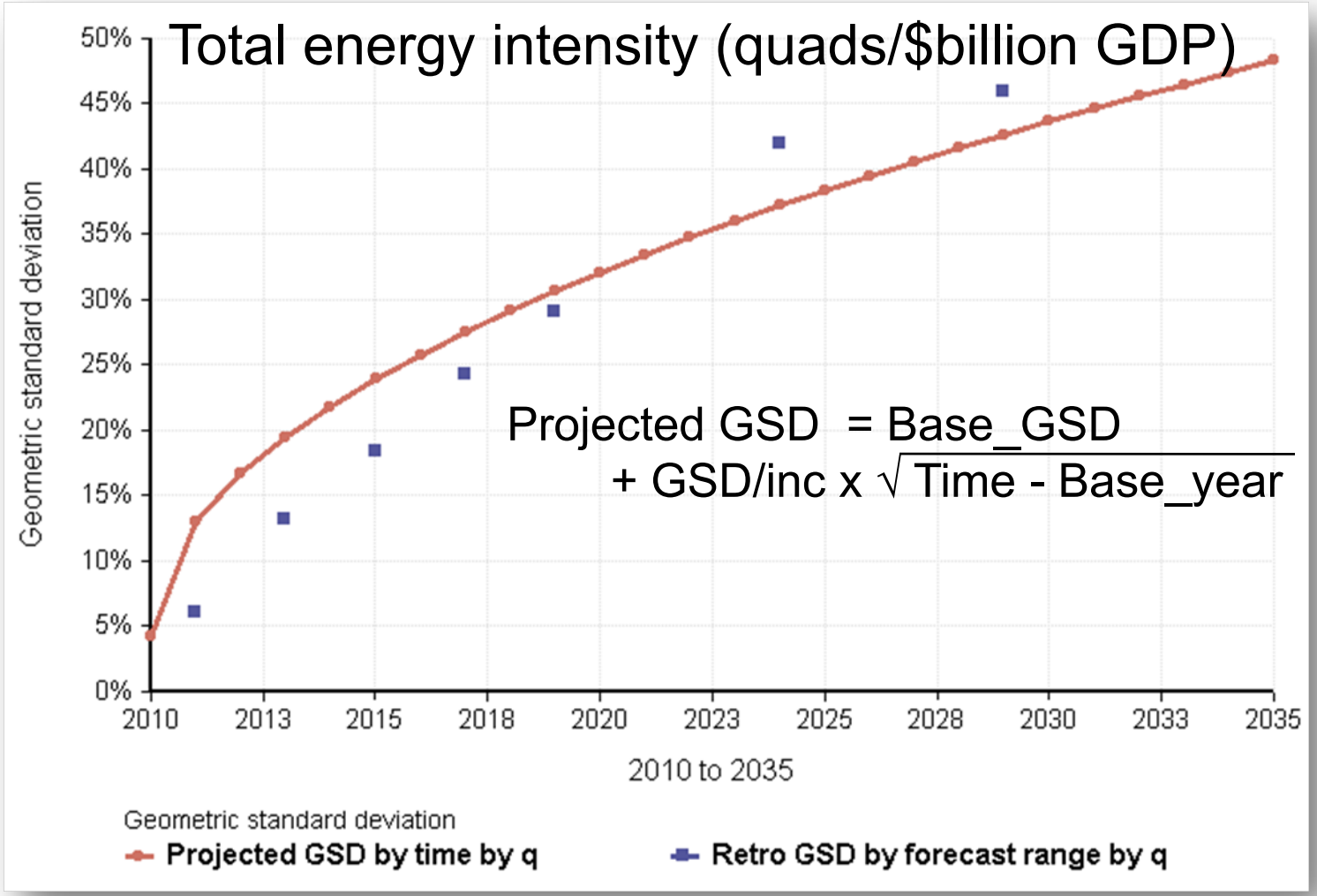
Error by forecast time range:
(geometric standard deviation)



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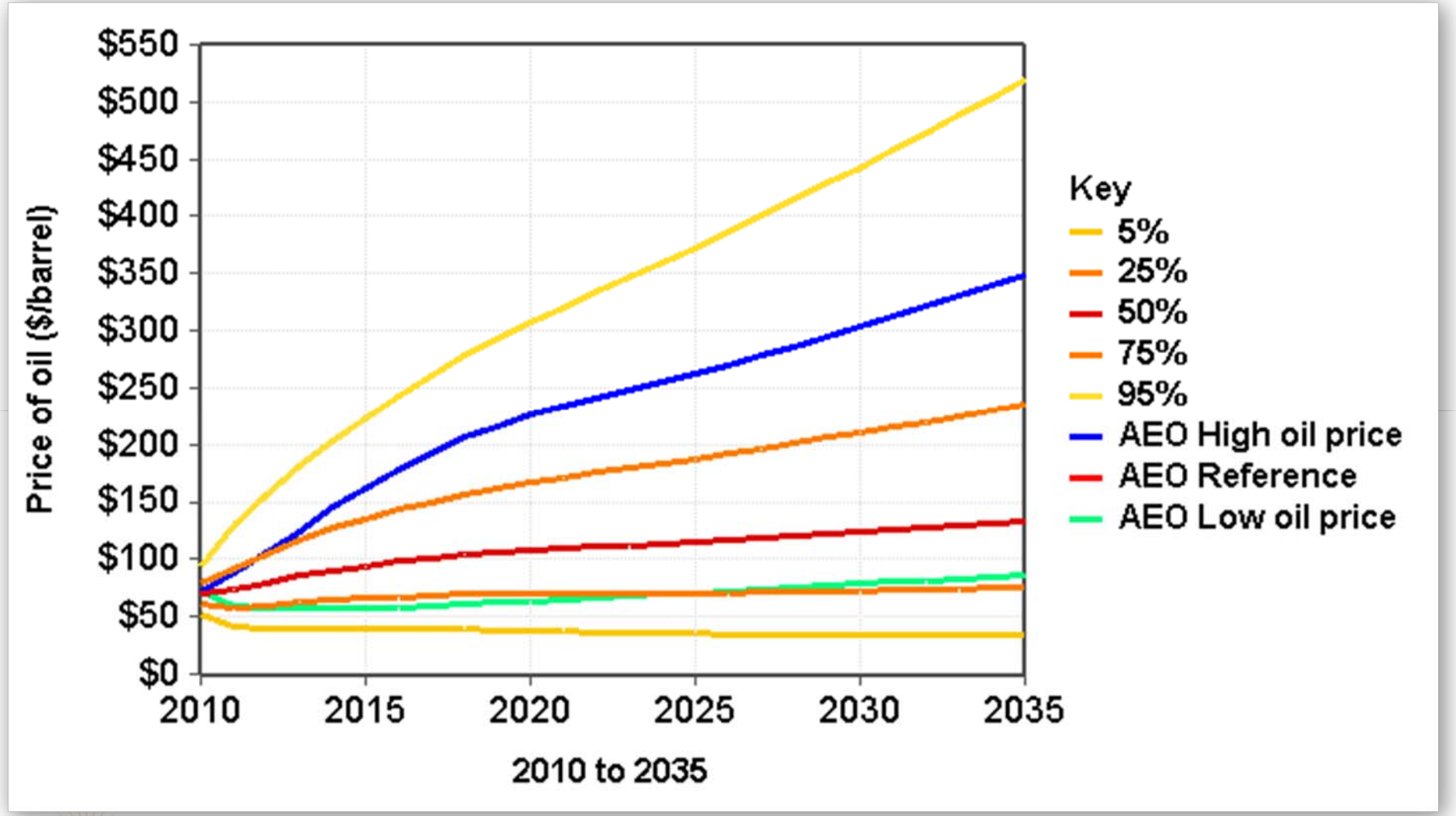
Oil price

AEO scenarios vs. percentiles of probabilistic forecasts



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Uncertainty assessment from retrospective error analysis of forecasts: Some observations

- Some types of quantity (e.g. prices) are less predictable than others (e.g. energy flows).
- You need a long history for useful calibration
- Forecast error distributions have long tails — not Gaussian.
- Assumes that the future is as (un)predictable as the past.
- Complementary to expert elicitation

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Open-source policy modeling:
A modest proposal

All computer models used by governments to evaluate or justify public policy should be *open source.*

That is, the source program code should be available for anyone to download, review, run, and modify.

Does this mean we must use only open-source tools?

No. We can still use proprietary software, like Microsoft Excel, or Analytica — as long as the model code is public and the tool is easily available.

Max Henrion, "Open-Source Policy Modeling",
***I/S, J. of Law and Policy for the Information Society*, 2007**

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Why open-source policy models?

- Anyone — policy analysts, industry, NGOs, students, other agencies, interested public — should be able to review and critique assumptions, and explore sensitivity to changes.
- Inspired by open-source software
  - Firefox 43% of web browsers, Linux runs 30% of servers, Apache 70% of web servers, My SQL 44% of database systems,.
- And by open-source content, notably Wikipedia
  - Accuracy close to Encyclopedia Britannica. Coverage many times larger.
- Improve quality? Detect and fix errors
  - "Given enough eyeballs, all bugs are shallow.'' Linus's Law, (*The Cathedral and the Bazaar*, Eric Raymond, 1996).
- Imagine a growing community of policy modelers comparing, reviewing, improving, and recombining each others' models.

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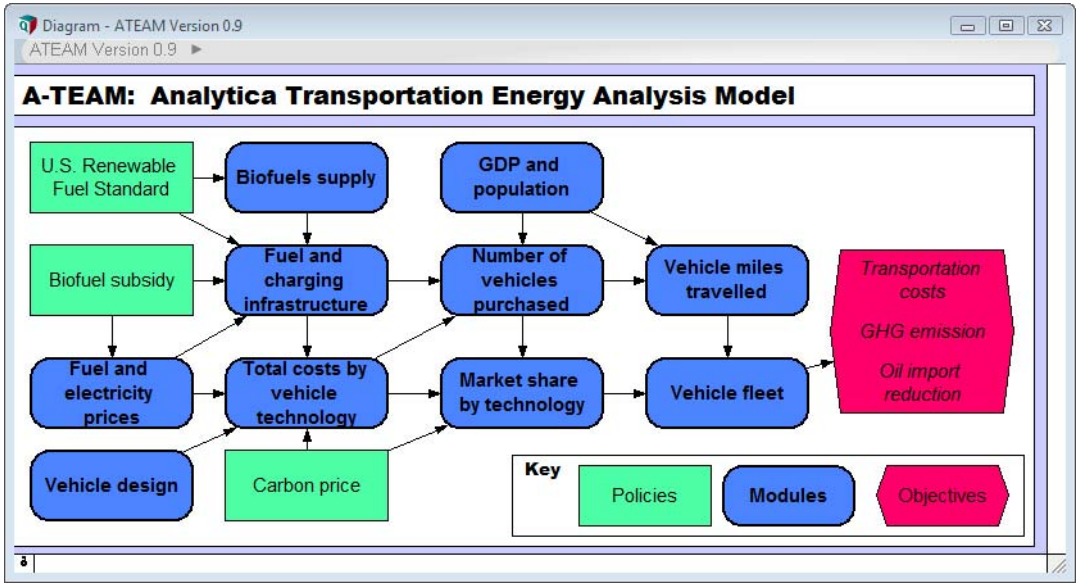
Summary

ATEAM is designed

- as a decision-analytic platform
- Available as open-source
- to encourage scrutiny and debate
- With sensitivity analysis to identify what matters and why to focus the discussion
- to facilitate exploration of multiple scenarios and explicit uncertainty



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Bringing clarity to difficult decisions