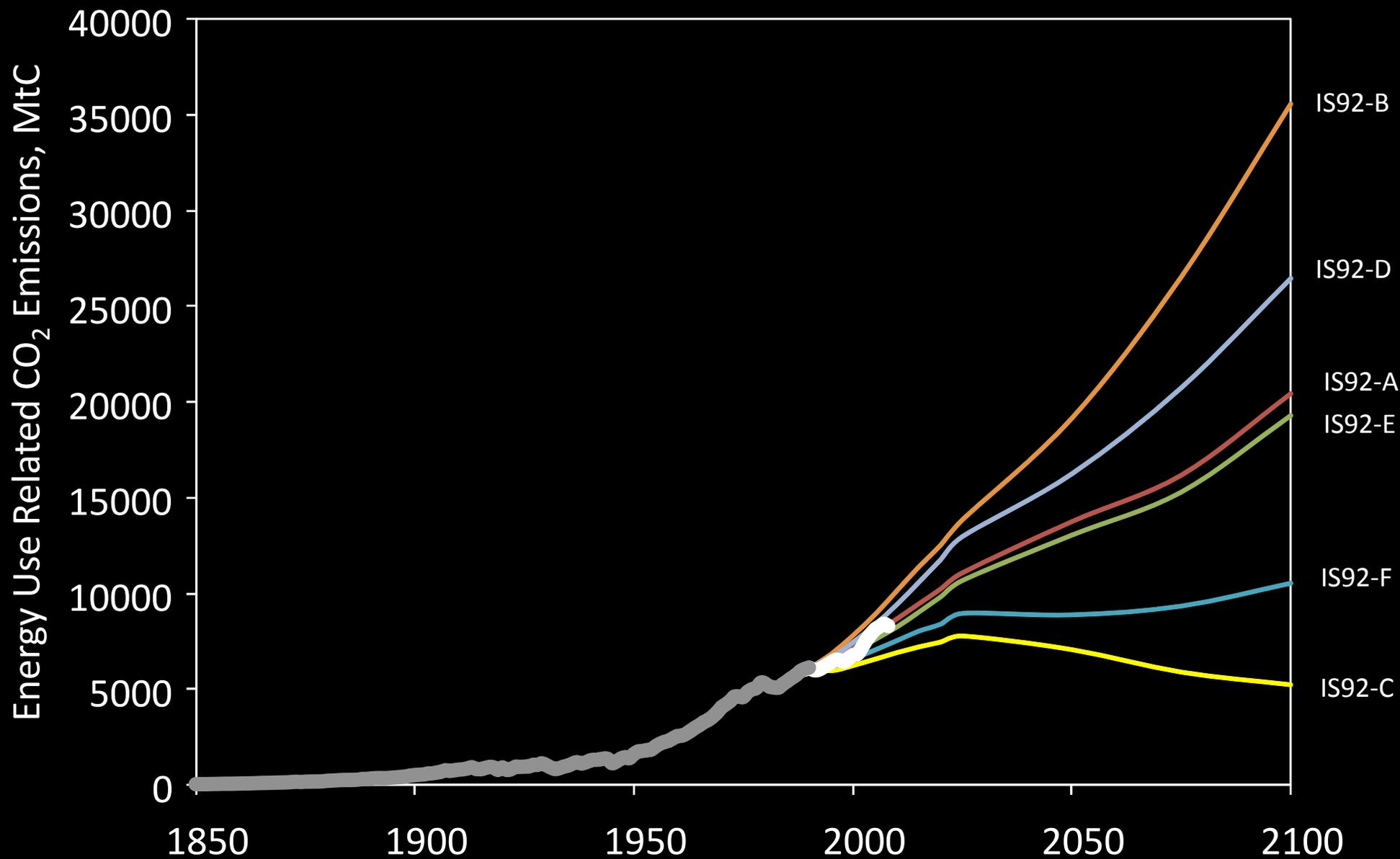


Global Mobility, Energy Use, and Climate Constraints

International Energy Workshop
Stanford University
July 6-8, 2011

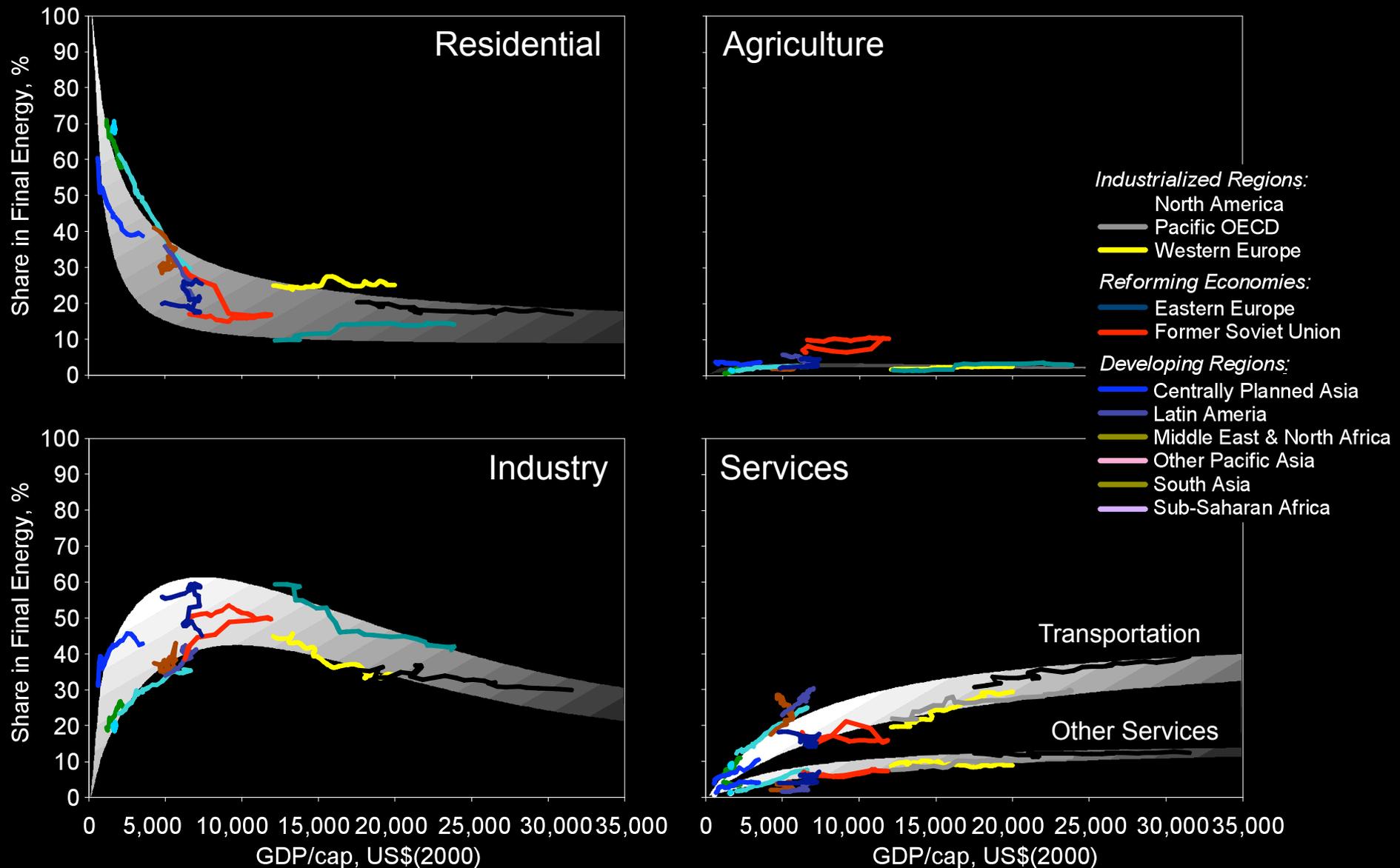
Andreas Schäfer
University of Cambridge & Stanford University
aschafer@stanford.edu

Trends in Energy-Related CO₂ Emissions

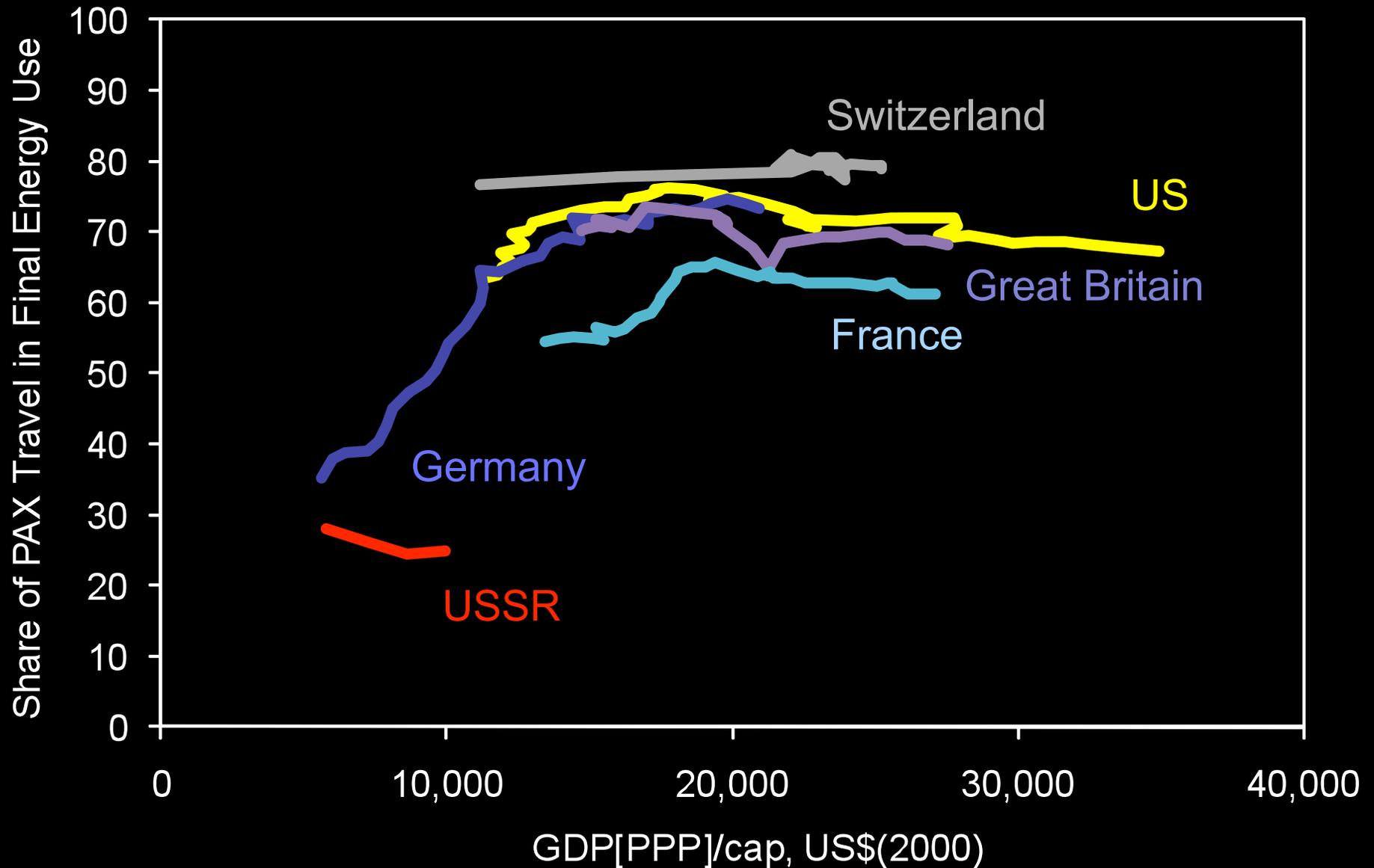


Structural Change in the Energy System

(Time series data from 1971 – 1998)



Share of PAX Travel Energy Use (preliminary numbers)



Objective

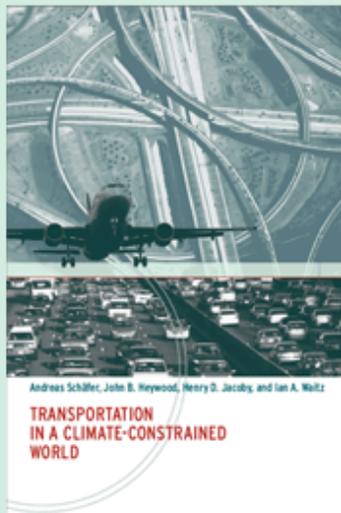
- Understand determinants of pax travel GHG emissions
- Examine opportunities for and constraints to reducing GHG emissions from pax mobility
- Assess likely impact of climate policy on transportation sector (travel demand, technological change, etc.)



Andreas Schäfer, John B. Heywood, Henry D. Jacoby and Ian A. Waitz

TRANSPORTATION IN A CLIMATE-CONSTRAINED WORLD

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Transportation in a Climate-Constrained World

Andreas Schäfer, John B.
Heywood, Henry D. Jacoby
and Ian A. Waitz

June 2009
6 x 9, 384 pp., 30 illus.
\$27.00/£17.95 (PAPER)
Short

ISBN-10: 0-262-51234-3
ISBN-13: 978-0-262-51234-3
MIT Press

In the nineteenth century, horse transportation consumed vast amounts of land for hay production, and the intense traffic and ankle-deep manure created miserable living conditions in urban centers. The introduction of the horseless carriage solved many of these problems but has created others. Today another revolution in transportation seems overdue. Transport consumes two-thirds of the world's petroleum and has become the largest contributor to global environmental change. Most of this increase in scale can be attributed to the strong desire for personal mobility that comes with economic growth.

In Transportation in a Climate-Constrained World, the authors present the first integrated assessment of the factors affecting greenhouse gas (GHG) emissions from passenger transportation. They examine such topics as past and future travel demand; the influence of personal and business choices on passenger travel's climate impact; technologies and alternative fuels that may become available to mitigate GHG emissions from passenger transport; and policies that would promote their adoption. And most important, taking into account all of these options, they consider how to achieve a more sustainable transportation system in the next thirty to fifty years.

[[transport and climate home page](#)]

NEWS

**Now in its second
edition with MIT Press**

Comprehensive Approach

- Analyze (and balance) supply *and* demand
- Global scale
- Role of historical data
- Analytical framework

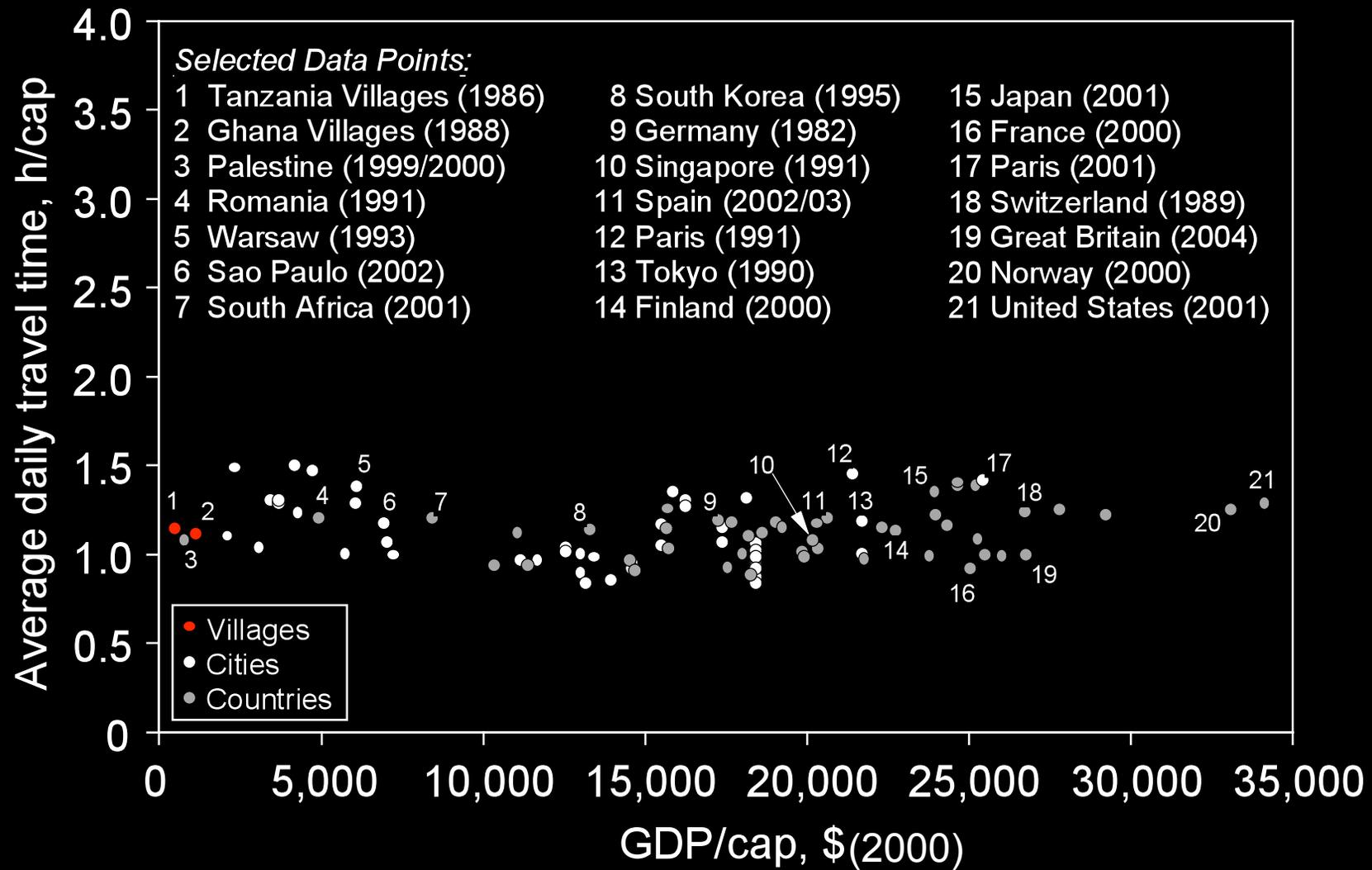
Greenhouse Gas Emissions: Identity

$$GGE = \frac{GGE}{E} \cdot \frac{E}{PKT} \cdot PKT$$

Modelling Global Travel Demand: Approach

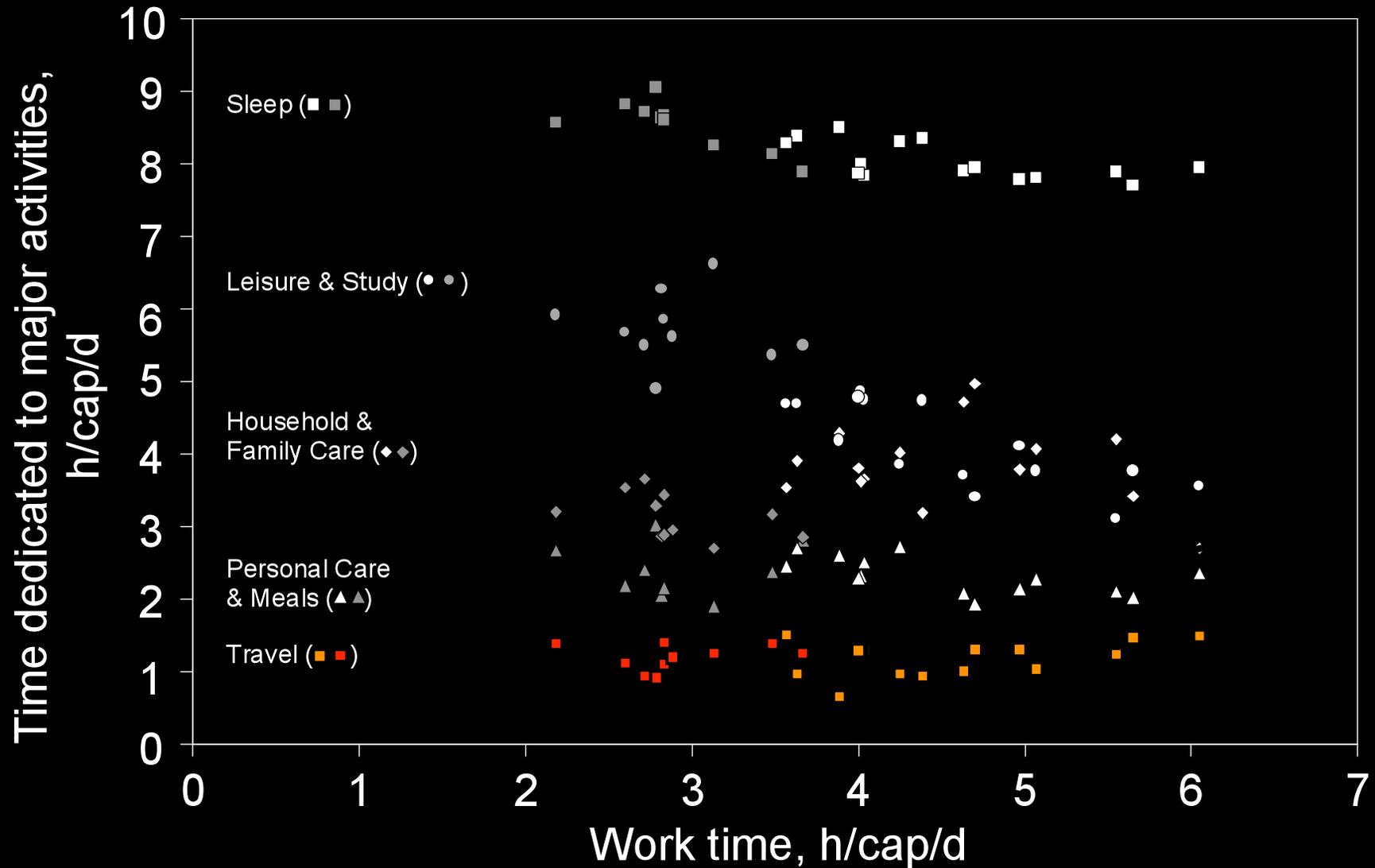
- 2-Step Process:
 - Growth model of total travel demand
 - Mode choice
 - (Potential 3. step: iteration)
- Discuss:
 - 1. Generation model, unconstrained transportation system (Schäfer and Victor)
 - 2. Generation model (Schäfer, while @PEEC)

Determinants of Travel Demand: TTB

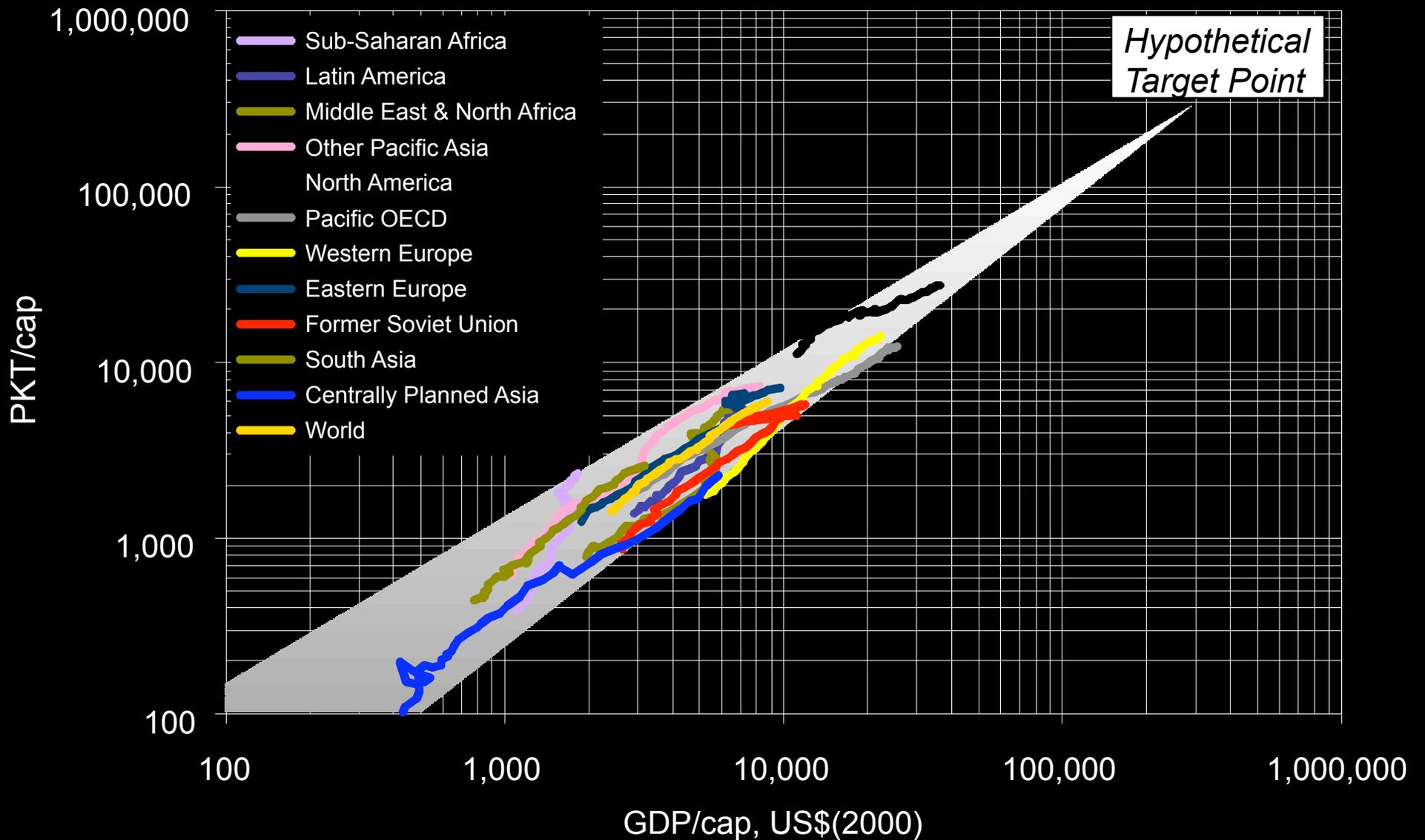


Travel Time Budget: Stability

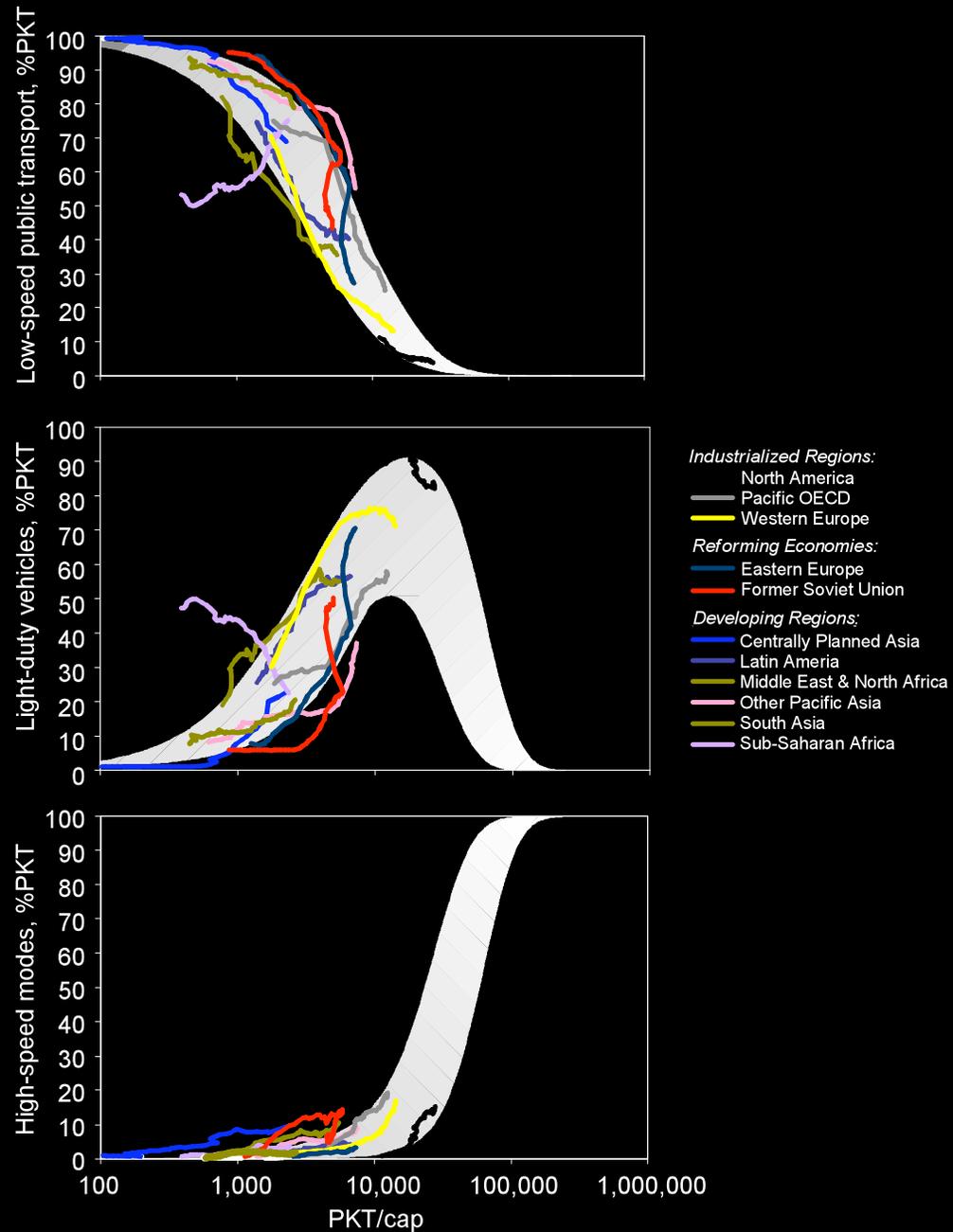
Time-use surveys, 1965/66 and early 2000s



Growth in Global Mobility (1950-2005)



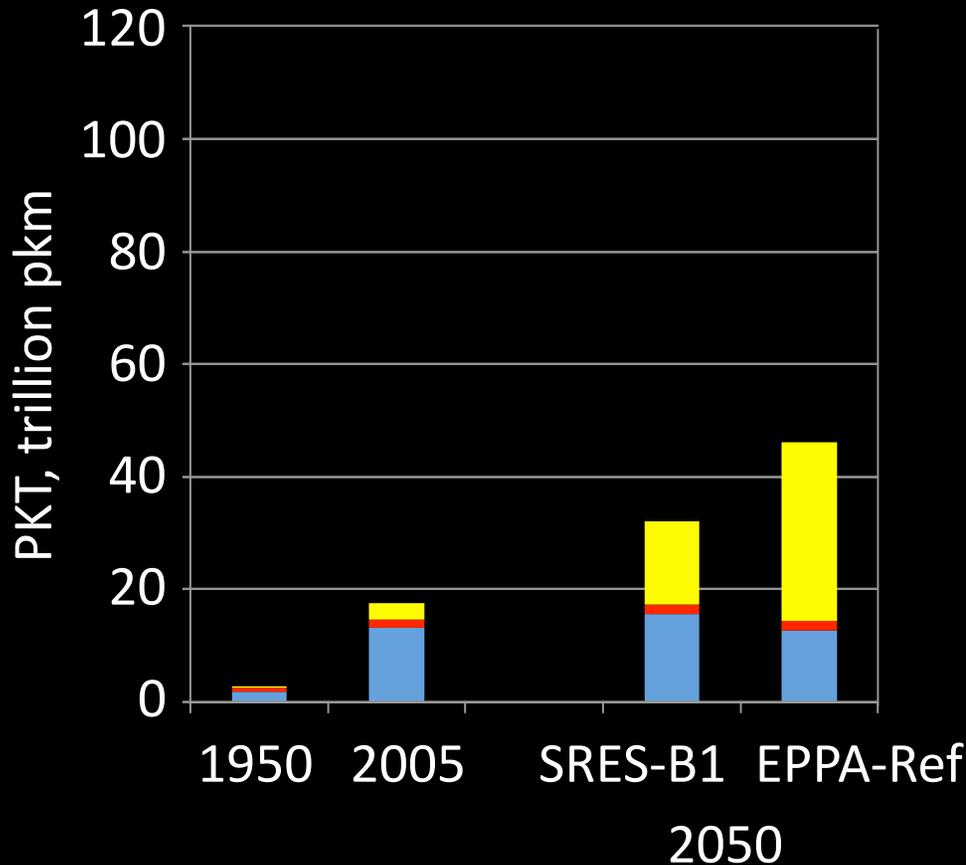
Shift from Slow to Fast (1950-2005)



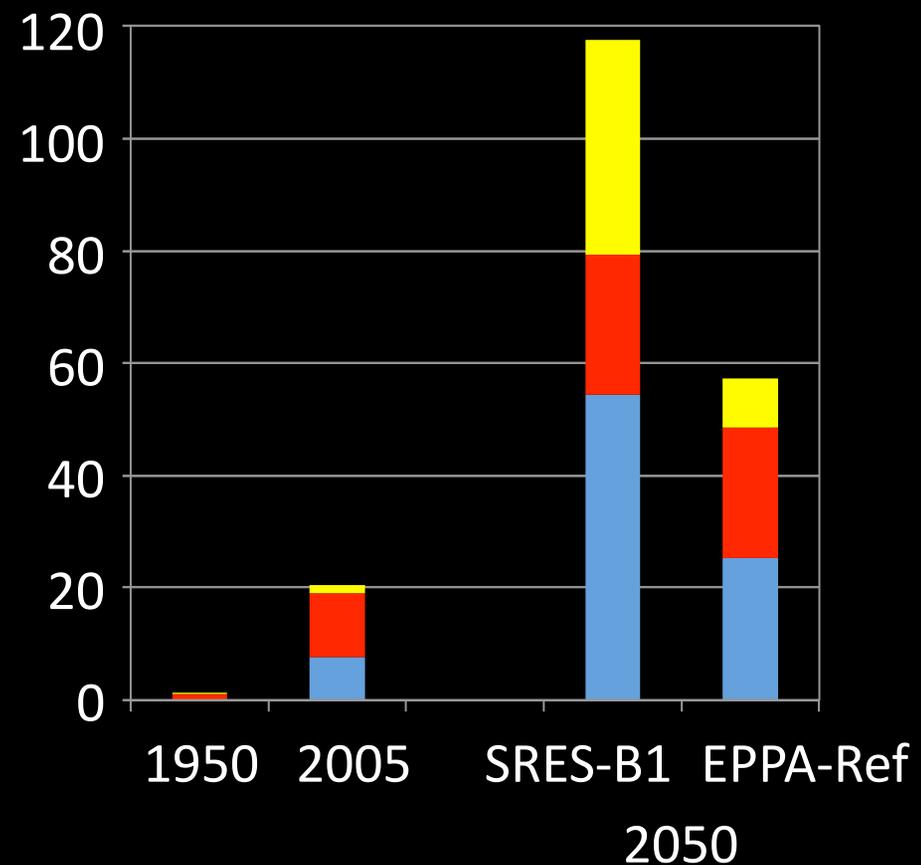
Shift from Slow to Fast (1950-2050)

(Travel Time Budget = 1.2 h/cap/d)

Industrialized Regions

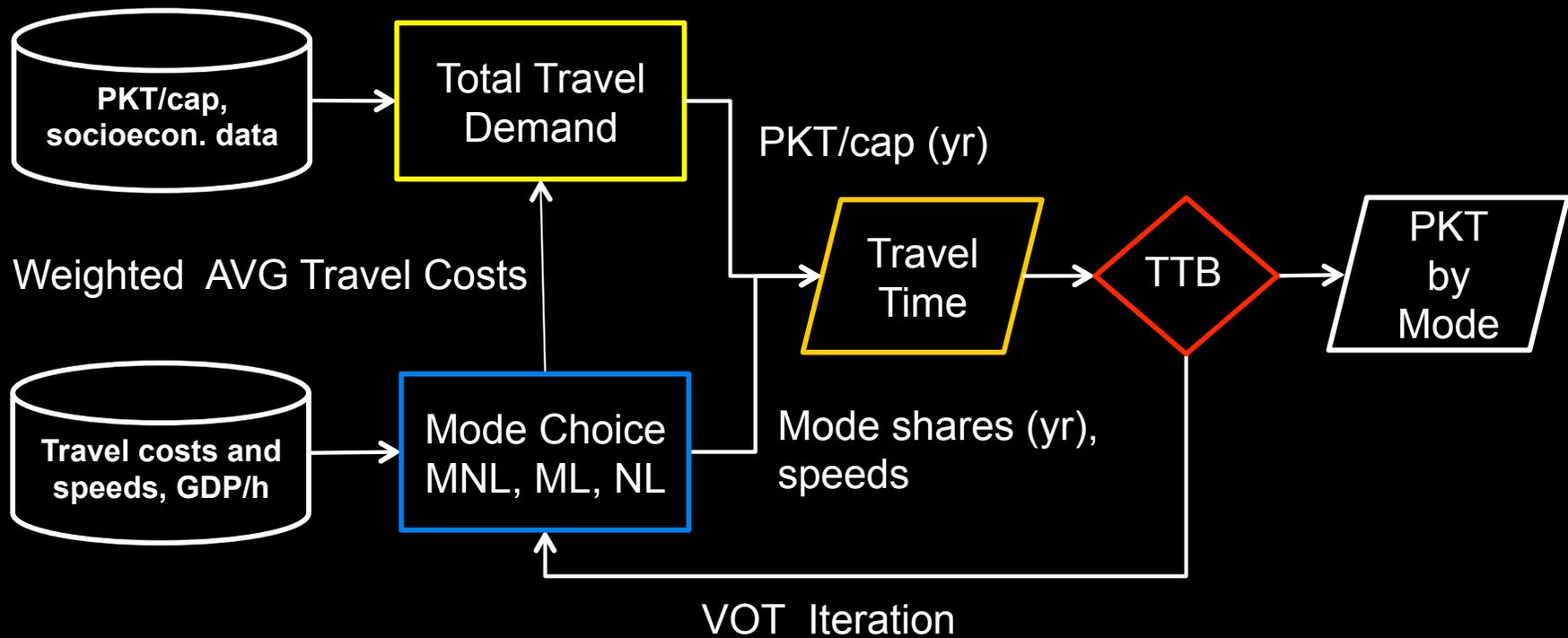


All Other Regions



- High-Speed Transportation
- Low-Speed Public Transportation
- Light-Duty Vehicles

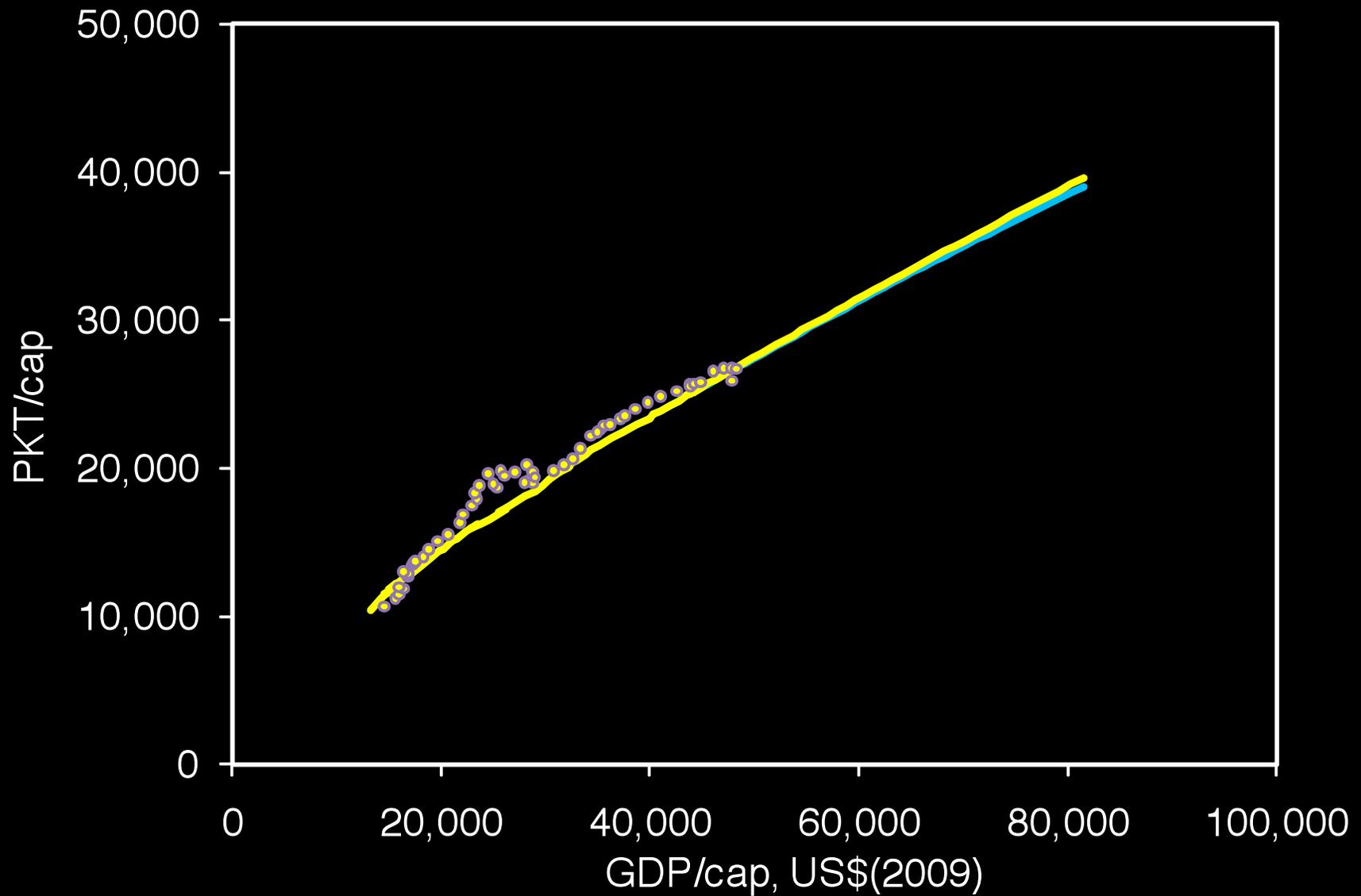
Second-Generation Model



Model Estimation and Implementation

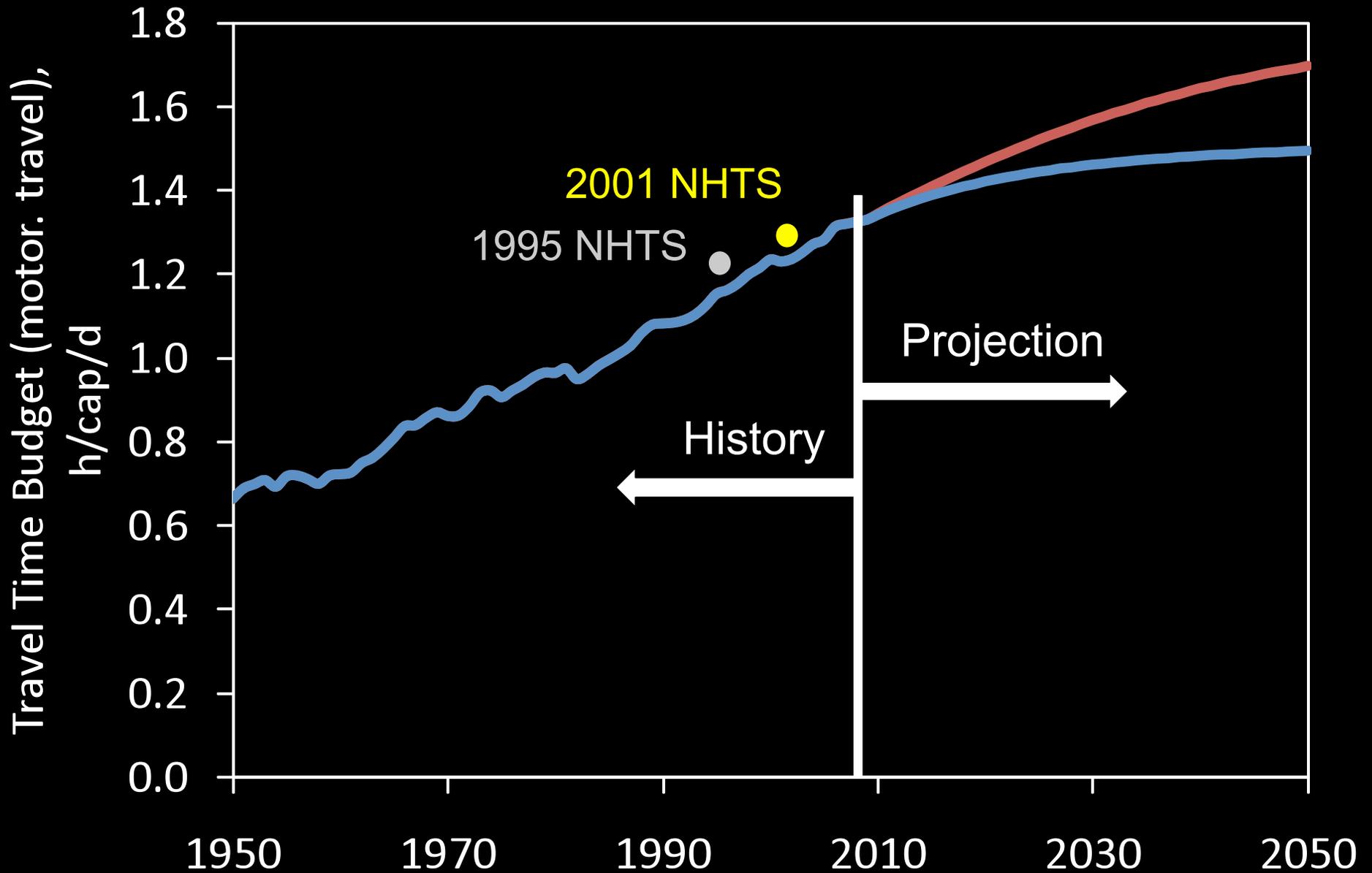
- First-order serial correlation
 - GLS (Prais-Winsten vs. Cochrane-Orcutt)
 - Manual iteration of choice model until ε_t and ε_{t-1} are statistically uncorrelated
- Estimated coefficients: $\alpha \approx 0.7$, $\beta \approx -0.1$,
VOT ≈ 0.4 , adj. $R^2 \approx 0.997$, all t-stats $\gg 2$
- Straightforward implementation: about 20 lines of code

Total Travel



Projected 2050 level is within 5% of “target point method” at given per capita growth of 1.5%/yr

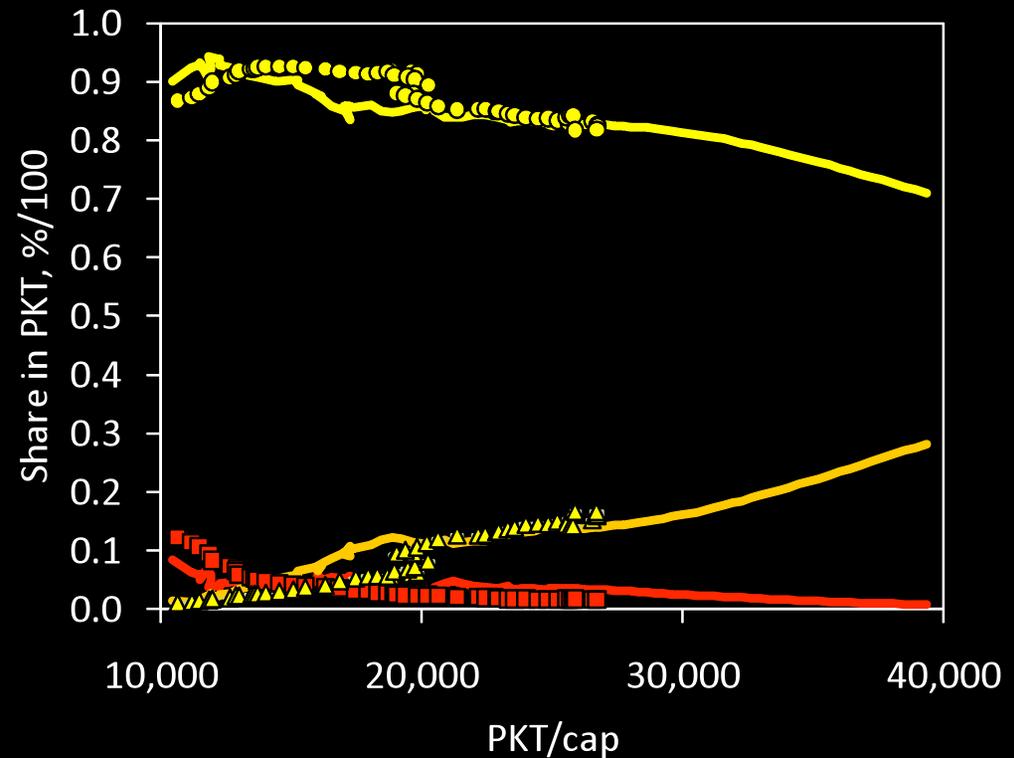
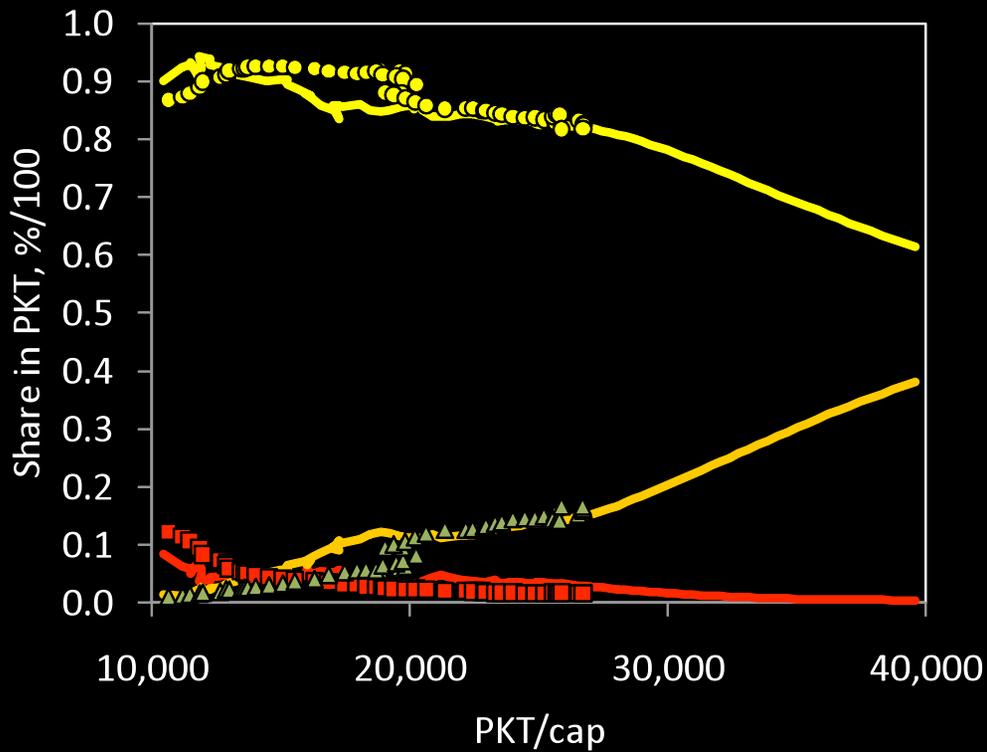
Mode Shares: TTB (motorized travel only)



Mode Choice

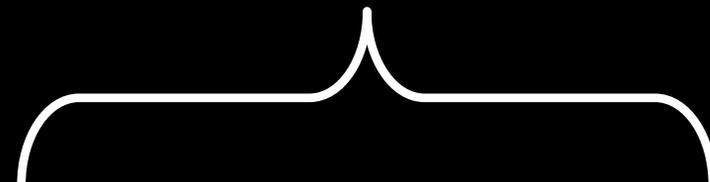
TTB (2050) = 1.5 h/cap/d
VOT(2050) = 0.60

TTB (2050) = 1.7 h/cap/d
VOT(2050) = 0.53

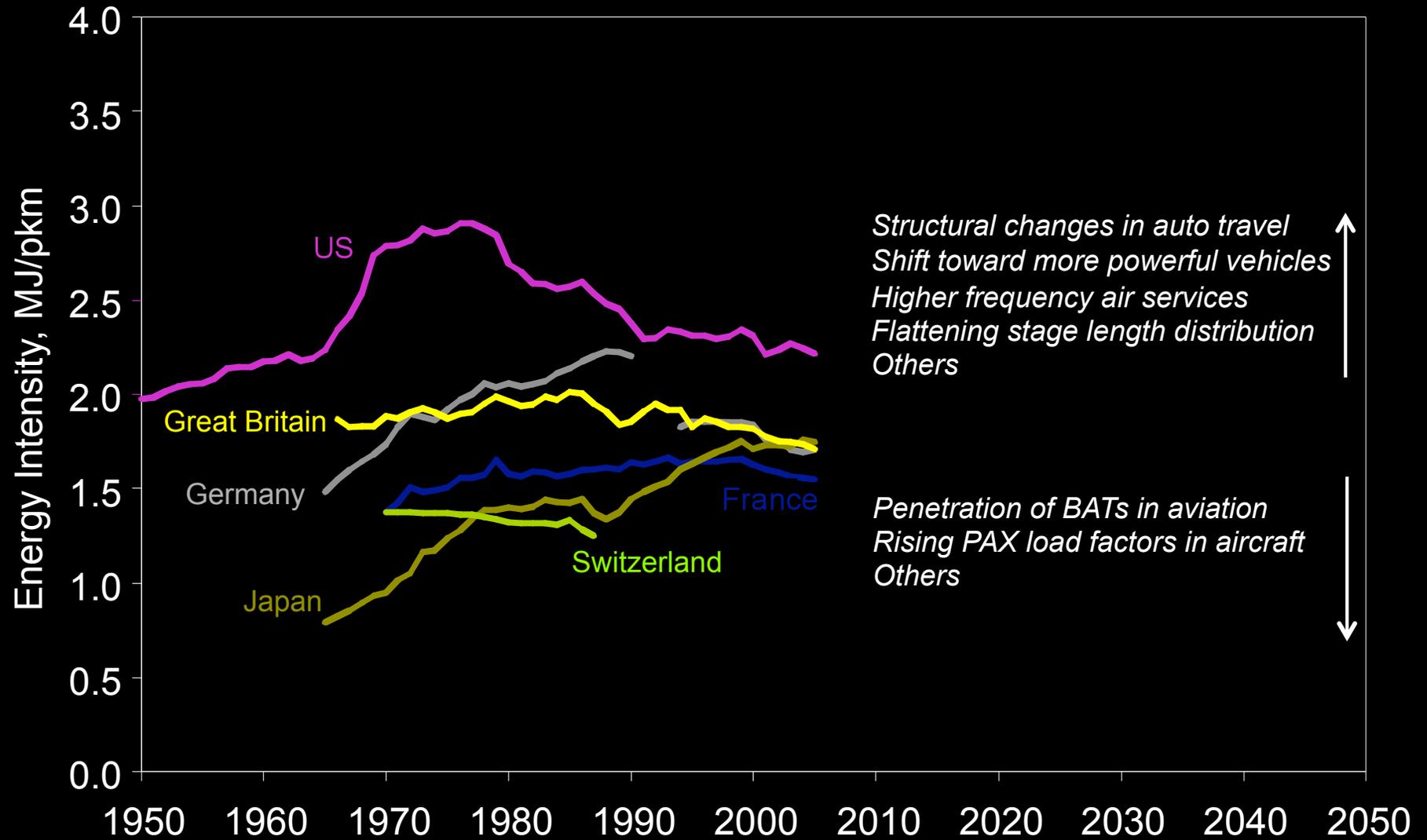


Energy Intensity

$$GGE = \frac{GGE}{E} \cdot \frac{E}{PKT} \cdot PKT$$


$$\frac{E}{VKT} \cdot \frac{VKT}{PKT}$$

E/PKT: Trends in Energy Intensity



Adding Up: Global Mobility CO₂ Emissions

Constant Technology Scenario (emissions in mill. tons)

	1950	2005	2050
Industrialized World	326	2,530	5,940 (4,640)
North America	264	1,440	2,960 (2,630)
Western Europe	44	818	2,330 (1,560)
Reforming Economies	16	196	591 (646)
Developing Economies	29	1,160	4,510 (12,800)
World	371	3,890	11,000 (18,100)
Relative amount, 2005 = 100	9	100	284 (465)

Opportunities for Reducing GHG Emissions

$$GGE = \frac{GGE}{E} \cdot \frac{E}{PKT} \cdot PKT$$

$$\frac{E}{VKT} \cdot \frac{VKT}{PKT}$$

Opportunities for Reducing E/PKT

Road Vehicles:

$$\frac{E}{VKT} = \frac{1}{\eta_{\text{Propulsion System}}} \cdot (A + D + R)$$

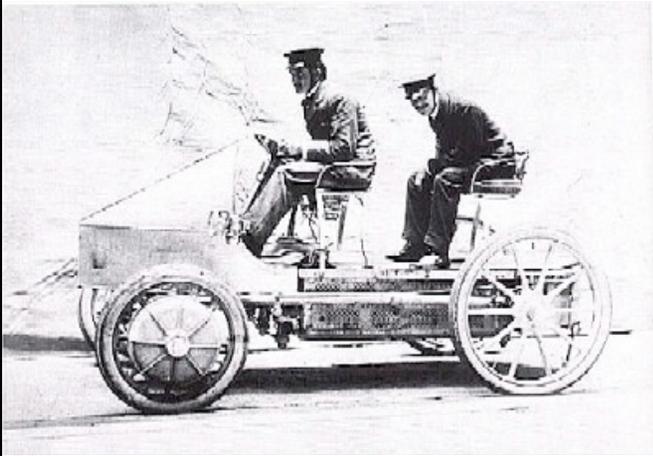
Jet Aircraft:

$$\frac{E}{PKT} = \frac{Q \text{ SFC}}{PAX \ V \ (L/D)} \cdot \frac{W_F}{\ln \frac{W_0}{W_0 - W_F}}$$

Constraints to Reducing E/PKT

- Engineering trade-offs
 - Occupant safety vs. automobile weight, etc.
 - Larger aircraft wingspan (to increase L/D) vs. increase in aircraft weight, etc.
- Consumer acceptance
 - Battery-electric vehicles vs. range, etc.
 - Turboprop aircraft engines vs. passenger comfort, etc.
- Development costs of new (road and air) vehicles several billion dollars → existing, proven designs
 - Evolutionary process implies that many fuel-saving technologies have long history

Long Technology History

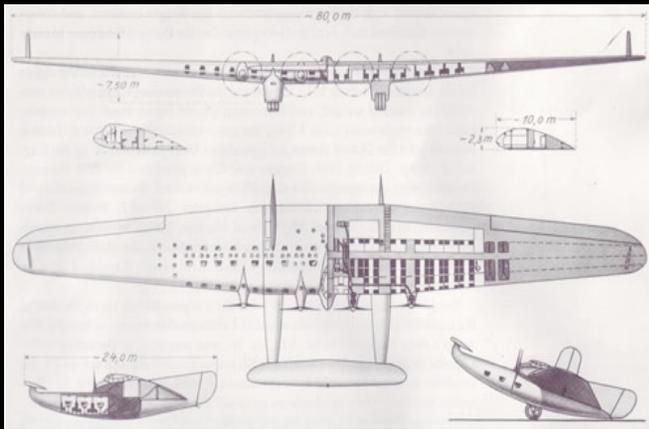


95 years



Racing version of the front wheel driven, petrol-electric Lohner "Porsche" in 1900.

<http://www.hybrid-vehicle.org/hybrid-vehicle-porsche.html>



100+ years?



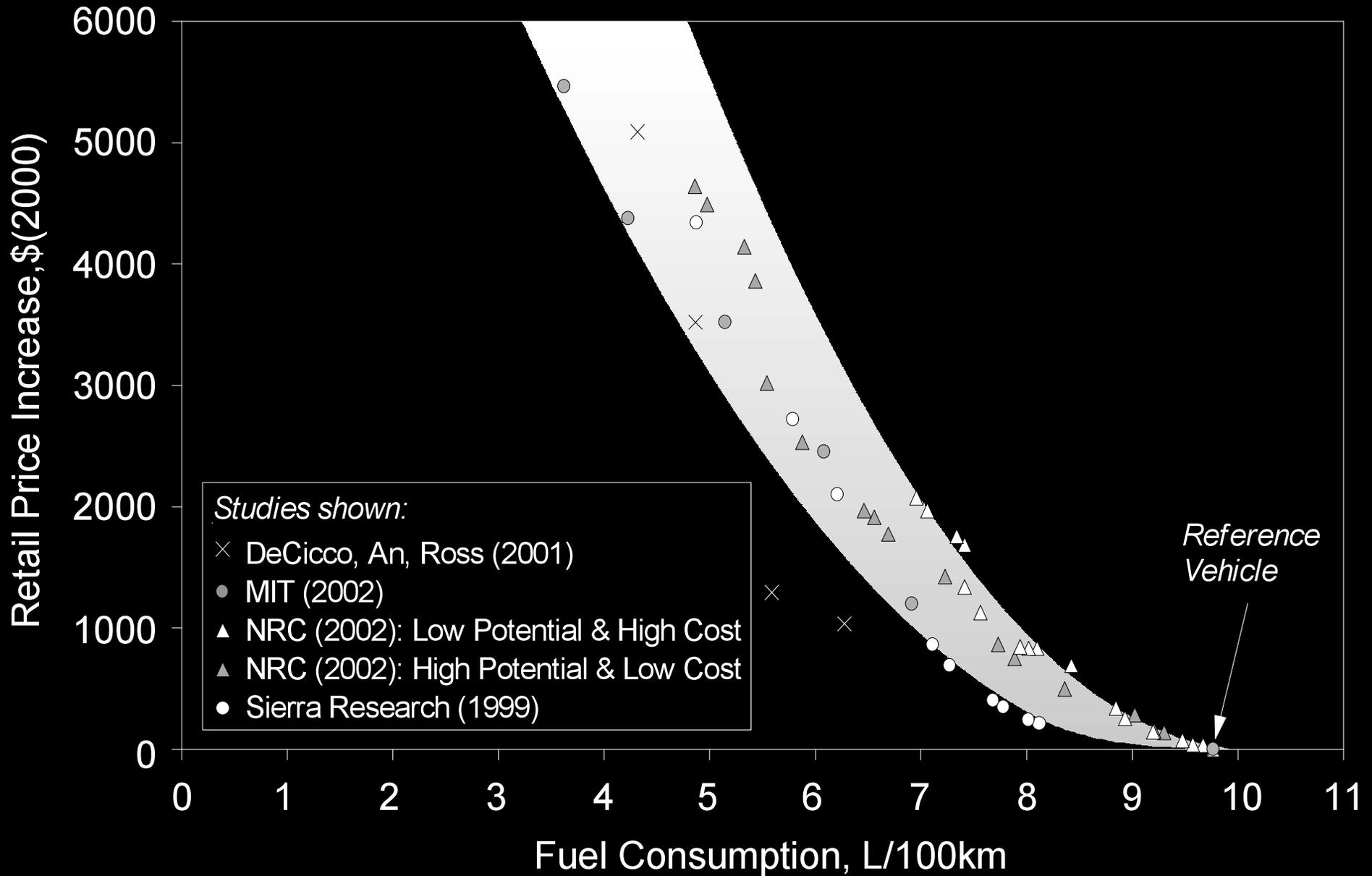
Hugo Junkers' 1924 design for a giant flying wing. The wing was to accommodate 26 cabins for 100 passengers, carry a crew of 10, and have enough fuel for 10 hours of flight.

<http://www.century-of-flight.net/Aviation%20history/flying%20wings/Early%20Flying%20Wings.htm>

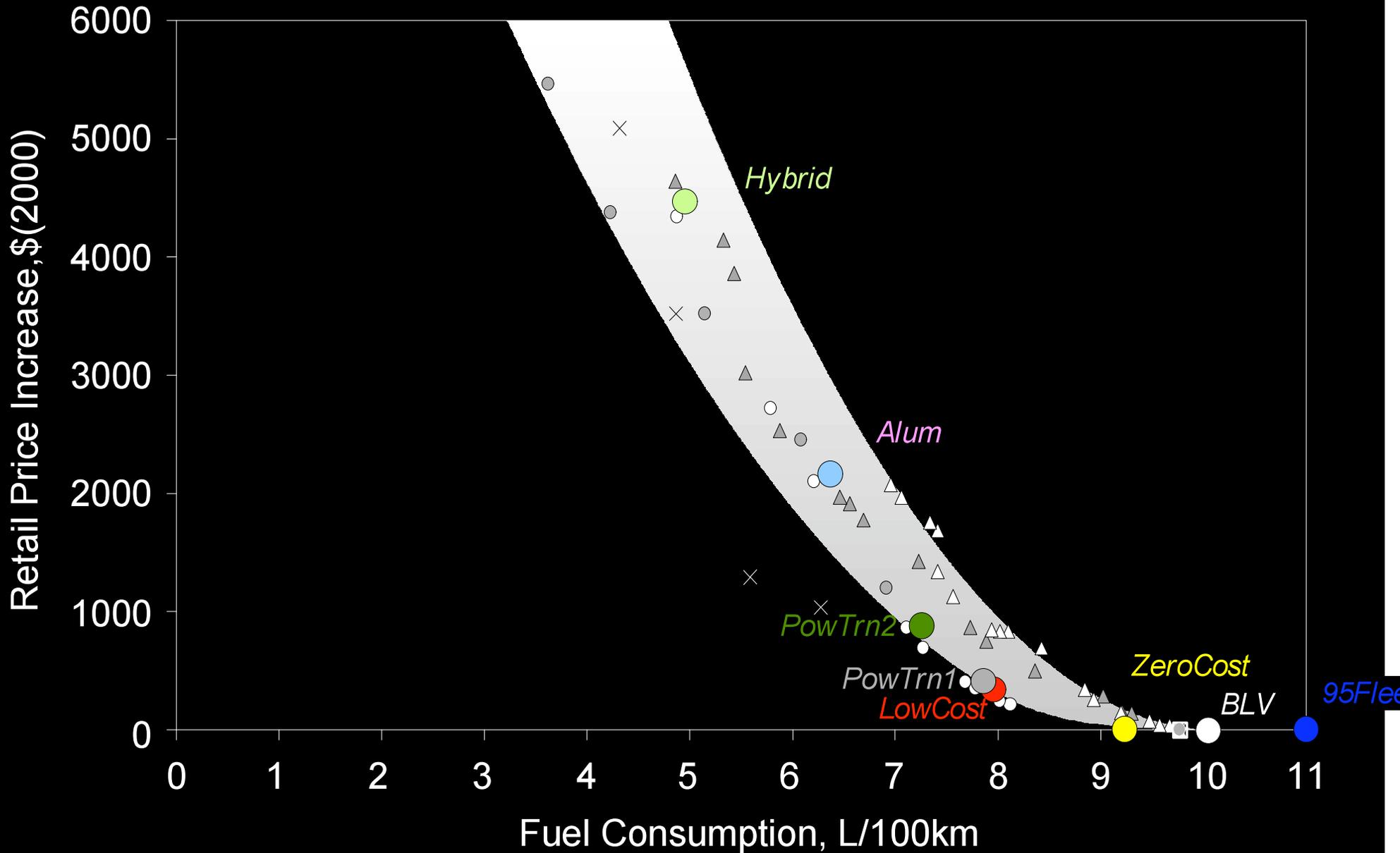
Opportunities for Reducing E/PKT: Summary (while maintaining current performance characteristics!)

- By mid' 2020s
 - E/PKT reduction potential \approx 30-50%
(for the average new LDV or aircraft
in early 2000, using technologies
currently under development)
- By midcentury
 - Natural fleet turnover would translate
these reductions to the vehicle fleet

Automobile Cost Curve: U.S.



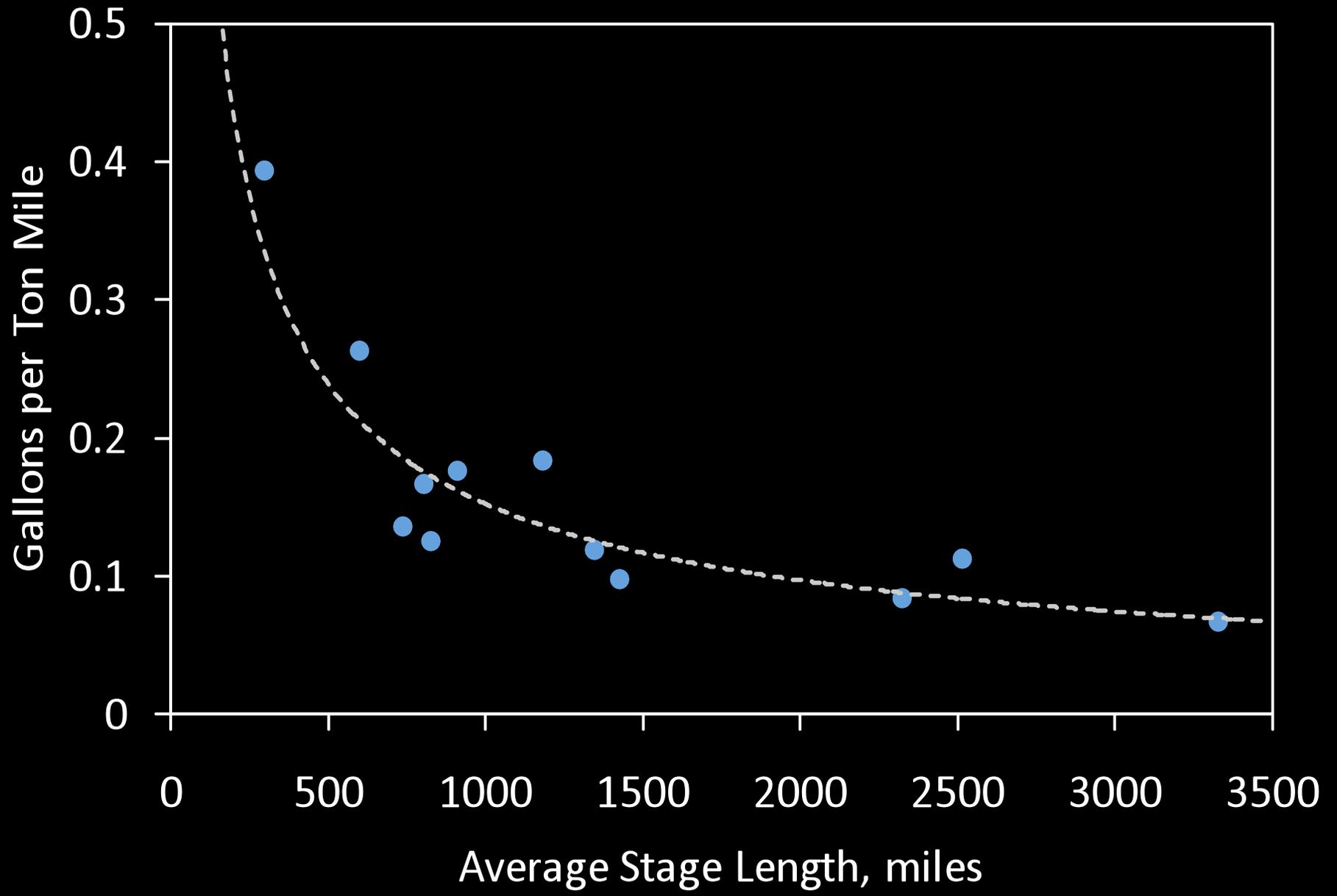
Automobile Cost Curve: U.S.



A Brief Look At Freight Transportation

- Joint research with Adrian Albert (demand) and Michael Gucwa (supply)
- Very similar patterns in demand and energy use
- Here only concentrate on truck and aircraft energy intensity

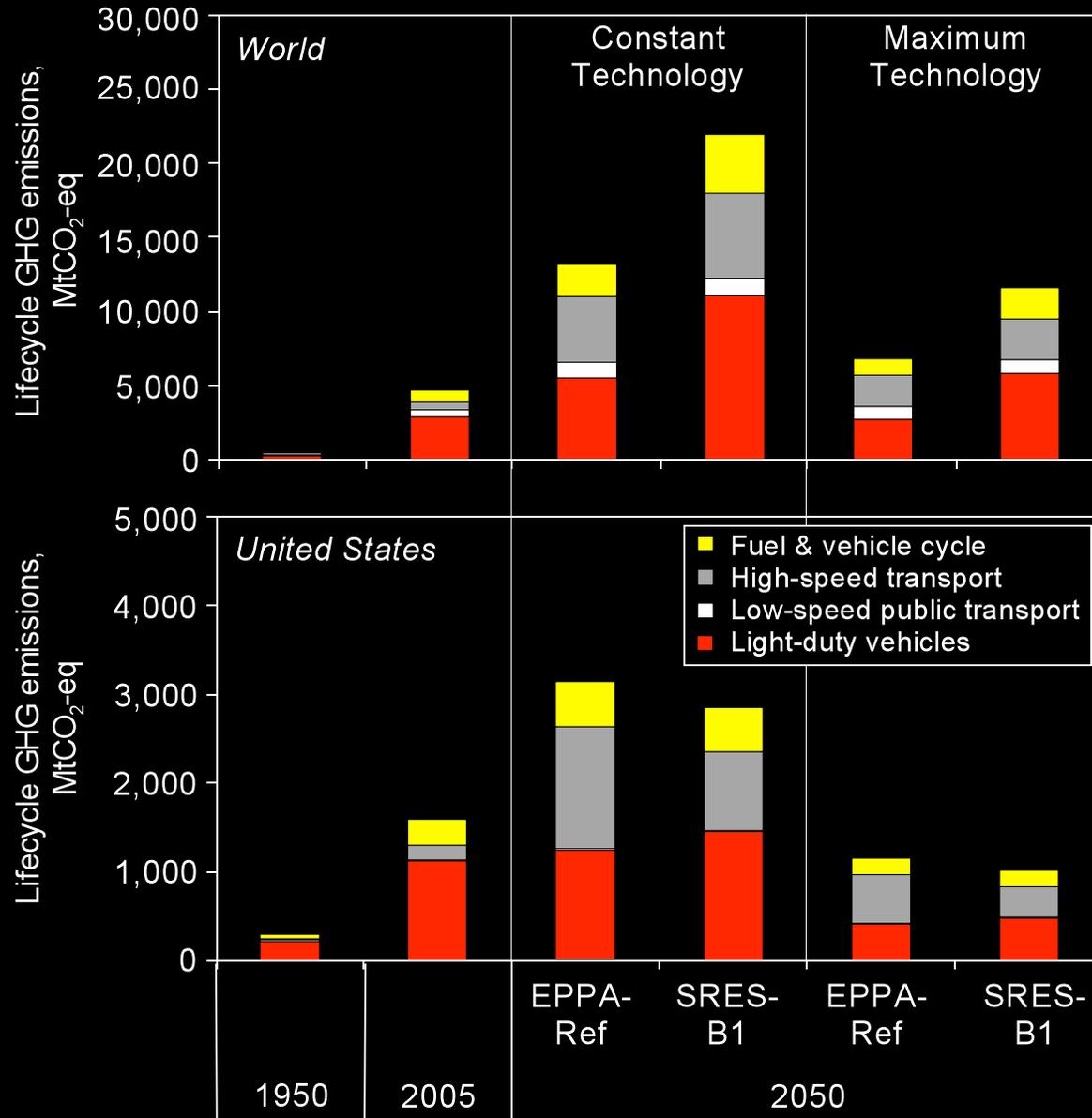
Energy Intensity of Freight Aircraft (US)



Future Prospects and Policy Choices

$$GGE = \frac{GGE}{E} \cdot \frac{E}{PKT} \cdot PKT$$

Technical Potential for Reducing GHG Emissions



Possible Contribution of Passenger Travel

United States transportation system, carbon prices from MIT-CCSP study

	LC GHG- Emissions MtCO ₂ -eq	Fuel Price \$/L	2. Generation Biofuel %Energy	Prevailing Technology
1950	300	0.32	0	
2005	1,600	0.47	0	2005 fleet
2050				
Constant Technology	3,130	0.41	≈ 0	Early 2000 tech.
Reference Case	1,450-1,730	0.72	25-10	Improved main-
550 ppm (CO ₂ -eq)	1,250-1,660	0.79	33-10	stream technology

Impact on travel demand negligible!

The Choices Ahead

- Government
 - Type of policy measure to change consumer and industry choice of new vehicle attributes (market-based / regulation / both)
 - Single policy approach vs. some portfolio of measures
 - Economy wide vs. passenger transport only
 - R&D investments
- Industry action depends upon government policy, BUT ...
 - GHG emission problem will not fade away (see structural change in energy use)
 - R&D investments (also) into reducing fuel consumption
 - Satisfies climate change *and* oil dependence
 - Importance of improving mainstream technology
- Need for behavioural change

Specification: Total Mobility

Identity: $\frac{PKT}{cap} = \frac{PKT}{Expd} \cdot \frac{Expd}{GDP} \cdot \frac{GDP}{cap}$

Regr. eqn: $\frac{PKT}{cap} = Const \cdot \left[\frac{GDP}{cap} \right]^\alpha \cdot P^\beta$



Challenge: P not available for most countries; α , β may change over long time scales

Specification: Mode Choice

- Choice of alternative with highest utility

$$U_{ij} = \alpha_0 + \alpha_1 \frac{1}{U_{ij}} + \alpha_2 \frac{U_{ij}}{T_h} + \varepsilon_{ij}$$

$$U_{ij} = \alpha_0 + \alpha_2 \frac{T_h}{U_{ij}} + \frac{U_{ij}}{T_h} + \varepsilon_{ij}$$

- Logistic CDF of error term: Logit

$$P_{ij} = \frac{e^{\alpha_0}}{\sigma_{ij} e^{\alpha_0}}$$

- Fit Logit, ML, NL to observed data
- Inputs: S_m , C_m , GDP/h

Climate Change

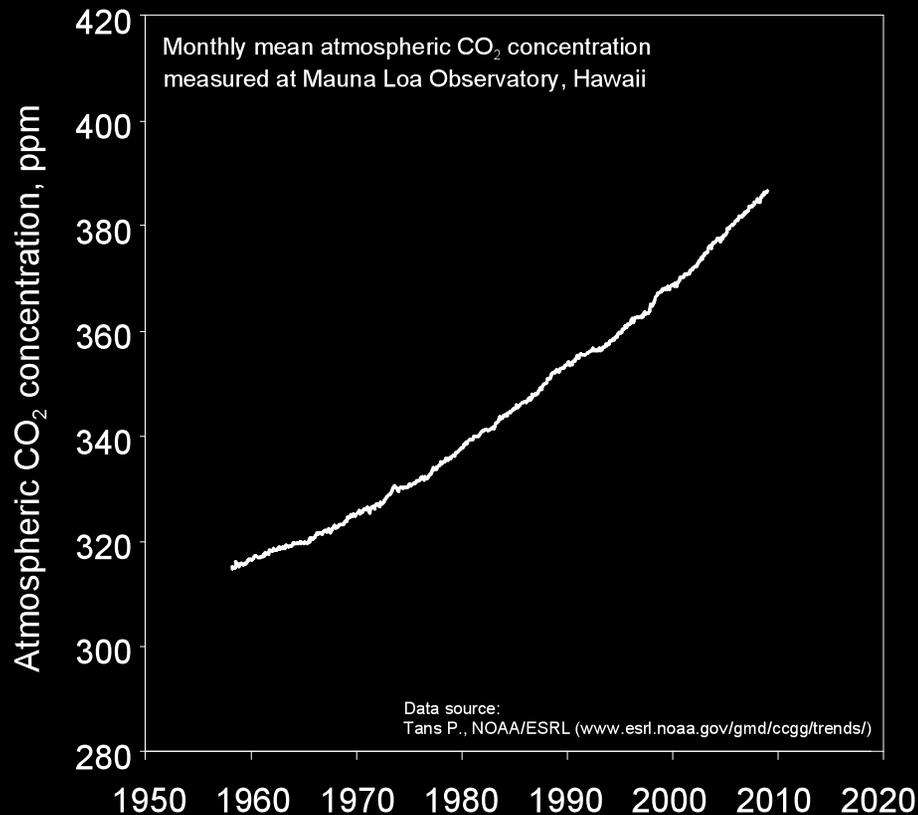
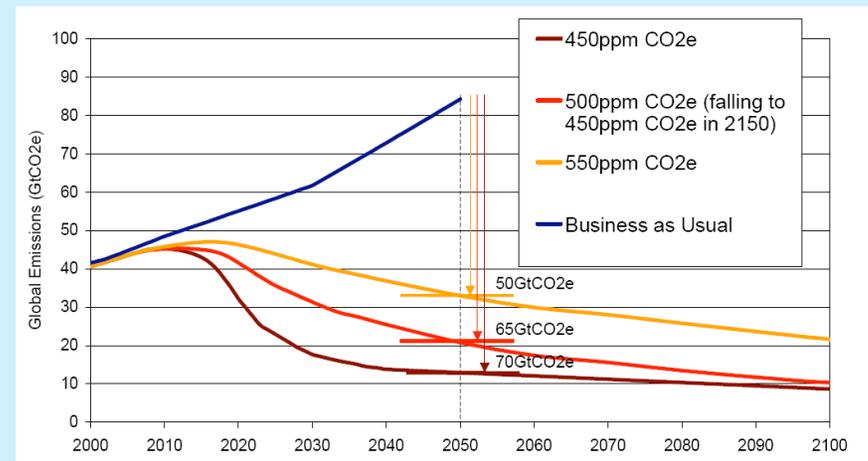


Figure 8.4 BAU emissions and stabilisation trajectories for 450 - 550 ppm CO₂e

The figure below shows illustrative pathways to stabilise greenhouse gas levels between 450 ppm and 550 ppm CO₂e. The blue line shows a business as usual (BAU) trajectory. The size of the mitigation gap is demonstrated for 2050. To stabilise at 450 ppm CO₂e (without overshooting) emissions must be more than 85% below BAU by 2050. Stabilisation at 550 ppm CO₂e would require emissions to be reduced by 60 – 65% below BAU. Table 8.2 gives the reductions relative to 2005 levels.



Stern Review (2006)