15.023J / 12.848J / ESD.128J Global Climate Change: Economics, Science, and Policy
Spring 2008

Growth, Technology & Emissions

- The reference or BAU projection: its uses
  - Understand the climate problem, its magnitude
  - Basis for analyzing mitigation measures
- Methods & puzzles in construction
  - “Horses for courses”
  - Underlying assumptions
- How the analysis is done
  - Simple growth models, myopic & forward-looking
  - Add an energy sector, and multiple regions
  - Multiple goods and energy types
  - Multiple regions & trade in goods & permits
- Sample results from a 3-model study

Emissions Projections
(Say, CO_2 to 2020)

- For MIT
  - –
  - –
  - –
- For the USA
  - –
  - –
  - –

Market-Based vs. Technology Cost

Top-Down **vs.** **Bottom-up**

- General equilibrium
  - Full economy
    - Goods, capital, labor
  - Prices endogenous
  - Factors driving growth
  - International trade
- Sacrifice technological detail
  - Production technology
  - Aggregation of sectors

- Engineering cost
  - Technical detail
  - Zero-cost opportunities
- Partial equilibrium
  - Key prices exogenous
  - Omit interactions
- Direct costs, ignoring
  - Consumer surplus loss
  - Industrial structure
  - Transactions costs

Hybrids

The Origin of CO_2 Emissions
(An accounting identity)

$$CO_2 = Pop * GDP/Pop * E/GDP * CO_2/E$$

Population

Per-capita standard of living

Energy efficiency of production

Carbon intensity of energy

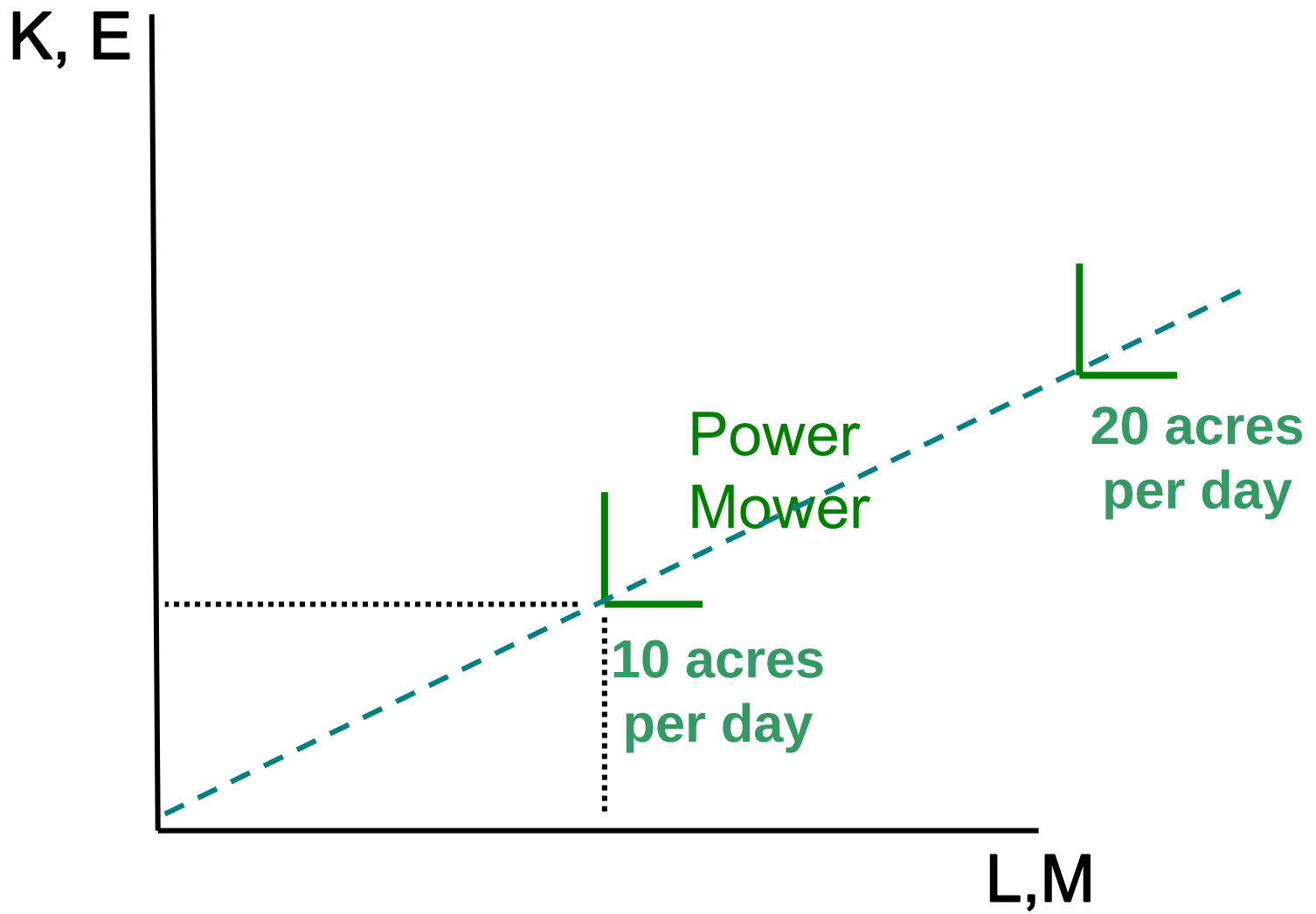
Non-CO_2 Human Emissions

- CH_4
  - Coal, gas and oil production
  - Landfills, livestock, rice production
- N_2O
  - Agricultural soils, chemical production
- Industrial gases
  - HFCs (air conditioning, foam blowing, solvents)
  - PFCs (semiconductor production, aluminum)
  - SF_6 (Insulator in electrical switchgear)
- Black carbon (aerosols)
  - Diesel engines, biomass burning
- Sox (aerosol precursor)
  - Coal burning

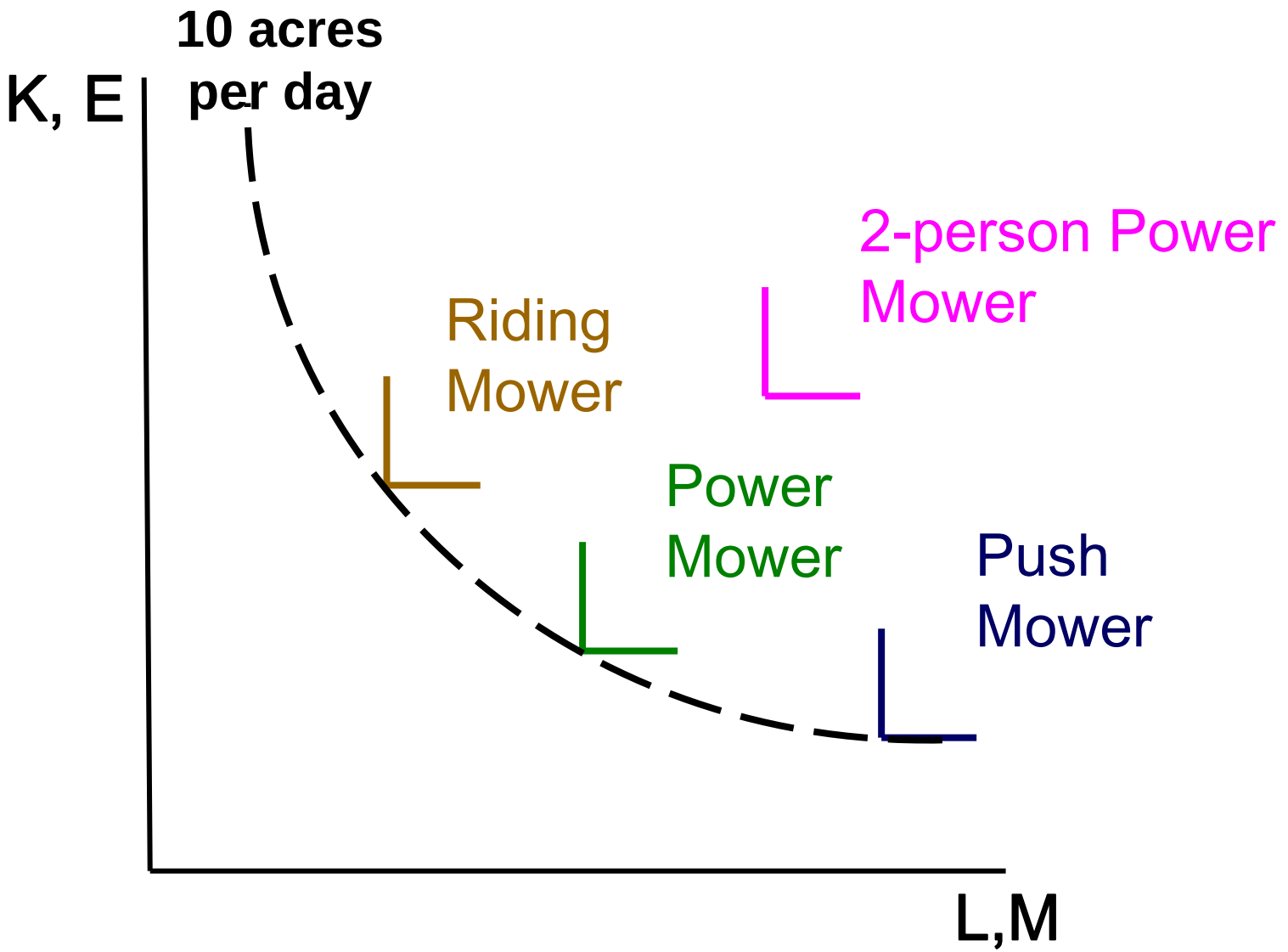
Components of a Projection Model

- Represent the production process
- Drivers of growth
  - Population
  - Productivity change
  - Growth in the capital stock
- Economic decisions (e.g., savings rate, consumer choice)
- Carbon emissions
  - Energy use
  - Carbon content of energy
- Calibrate to base year data

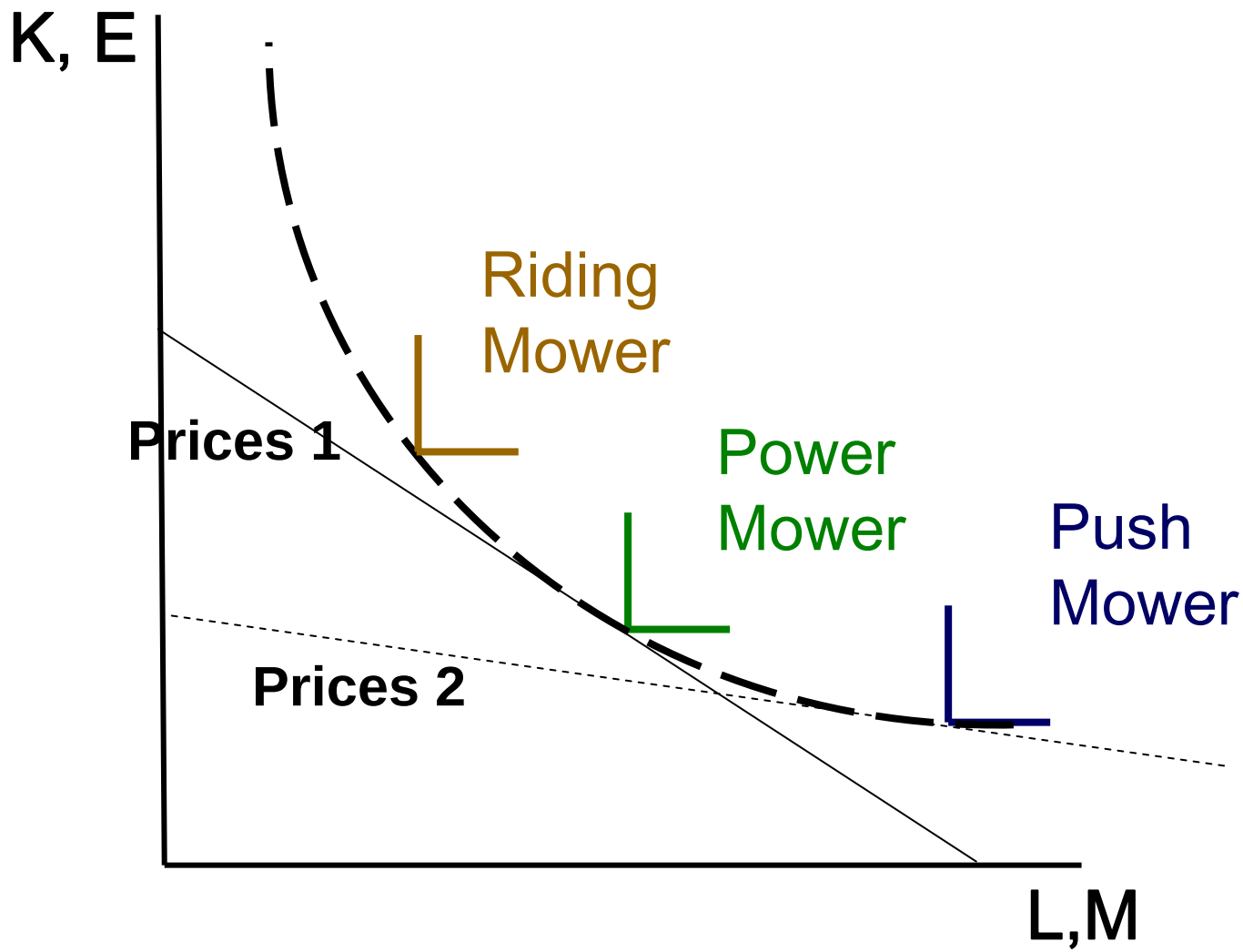
Technology: Cutting Grass



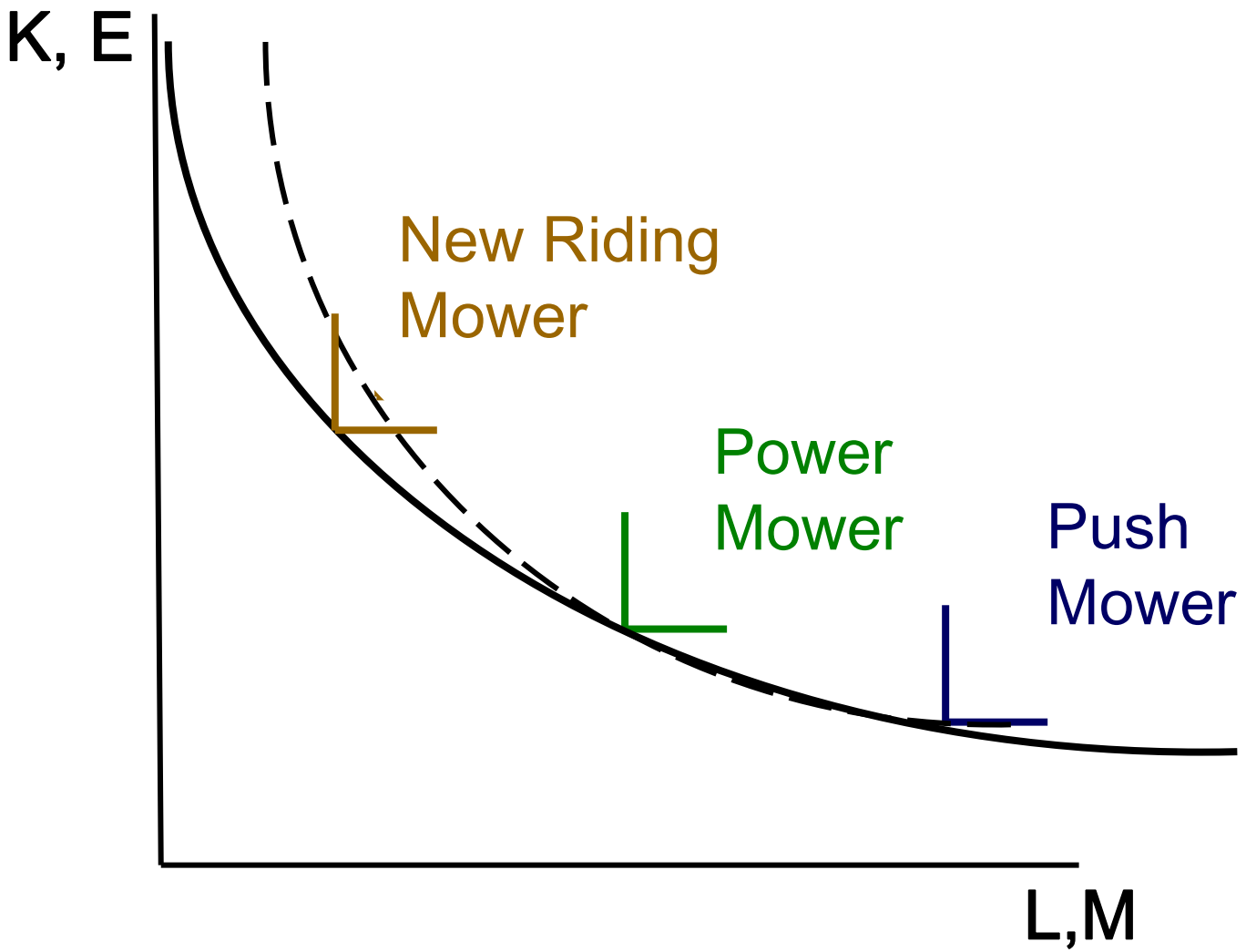
With Several Technologies



Technology Choice

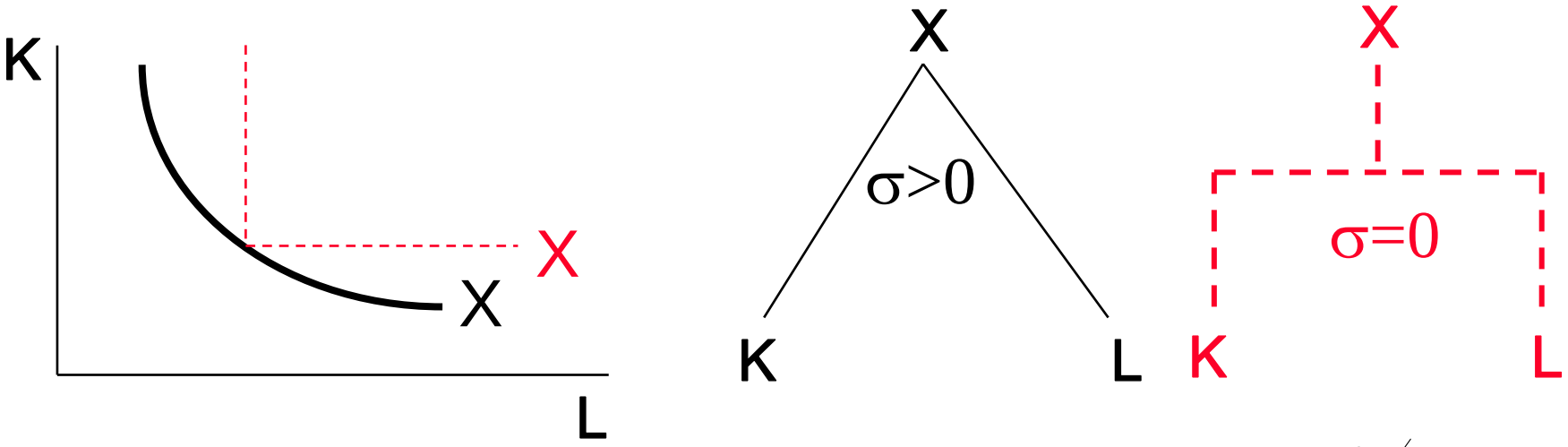


Technology Improvement



How Flexible Is the Economy?

Constant Elasticity of Substitution



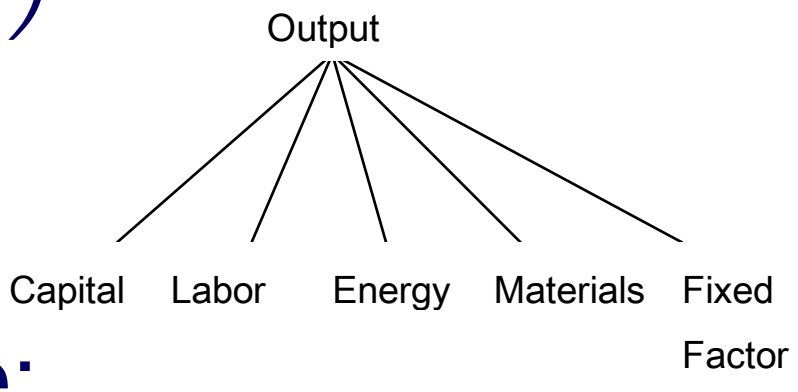
CES: $$X_t = \alpha_t (a_K K^{\rho^{KL}} + a_L L^{\rho^{KL}})^{1/\rho^{KL}}$$

$$\sigma_{KL} = \frac{1}{1-\rho^{KL}}$$

Extended Production Function

Other Input Factors to Production:

$q = f(K, L, E, M, FF)$



Technical Change:

Multi-factor Productivity: $q = a(t)\, f(K, L, E, M)$

Labor Productivity: $q = f(K, a(t)L, E, M)$

Energy Efficiency: $q = f(K, L, a(t)E, M)$

Endog. Tech. Change: $q = f(K, L, a(t, P_E)E, M)$

Simple "Top-Down" Model

- Simplifications
  - One output good (X)
  - One country (no trade)
  - "Parameterized" energy sector
  - No government (no taxes or transfers)
  - Recursive-dynamic (myopic): economic agents don't anticipate future prices
  - CO_2 only
- Relax these as we go forward

A Recursive Dynamic Model

$$X_t = a_t\left(b_K K^{\rho^{KL}} + b_L L^{\rho^{KL}}\right)^{1/\rho^{KL}}$$ Production function

$$L_t = L_0(1+\gamma)^t$$ Labor force growth

$$a_t = (1+g)^t$$ Productivity change

$$K_t = (1-\delta)K_{t-1} + I_t$$ Capital accumulation

$$X_t = C_t + S_t$$ Accounting Identity

$$S_t = I_t$$ Saving/investm't equilibrium

$$S_t = sY_t \qquad (Y \equiv X)$$ Savings behavior

$$E_t = f(X_t, t)$$ Carbon emissions

A Forward-Looking Model

$$X_t = a_t\left(b_K K^{\rho KL} + b_L L^{\rho KL}\right)^{1/\rho KL}$$ Production function

$$L_t = POP_0(1+\gamma)^t$$ Labor force growth

$$a_t = (1+g)^t$$ Technical change

$$K_t = (1-\delta)K_{t-1} + I_t$$ Capital accumulation

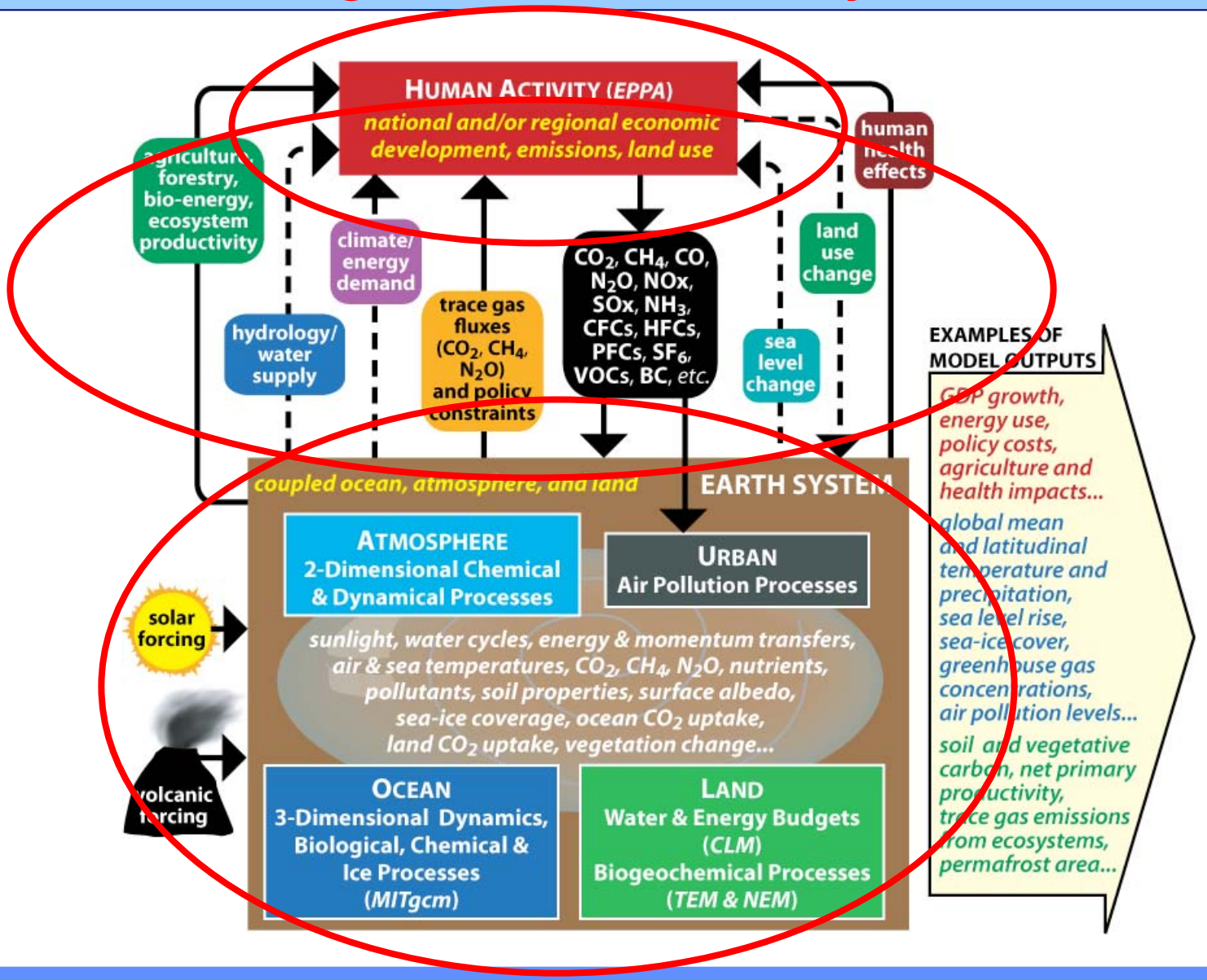
$$X_t = C_t + S_t$$ Accounting Identity

$$S_t = I_t$$ Saving/invest equilibrium

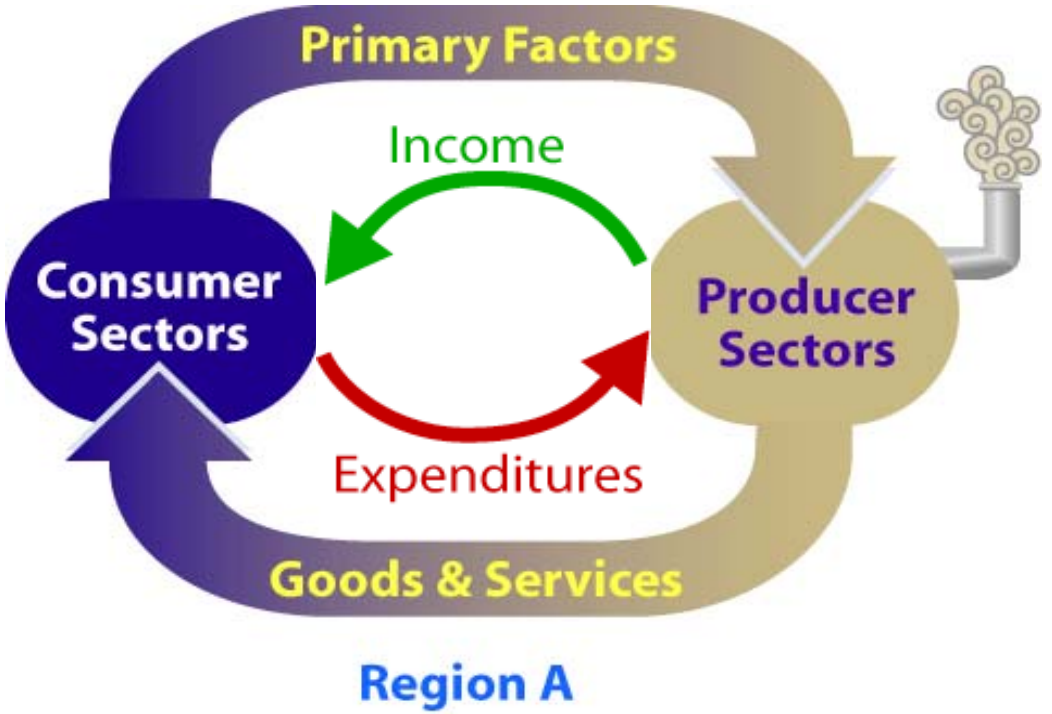
$$Max(W) = \sum_t \frac{f(C_t)}{(1+r)^t}$$ Maximize welfare (W)

$$E_t = f(X_t, t)$$ Carbon emissions

MIT Integrated Global System Model



Transactions In a Simple Economy



EPPA: Sectoral Aggregation

Sectors

Non-Energy
- Agriculture
- Energy Intensive
- Other Industry
- Services
- Industrial Transport
- Household Transport

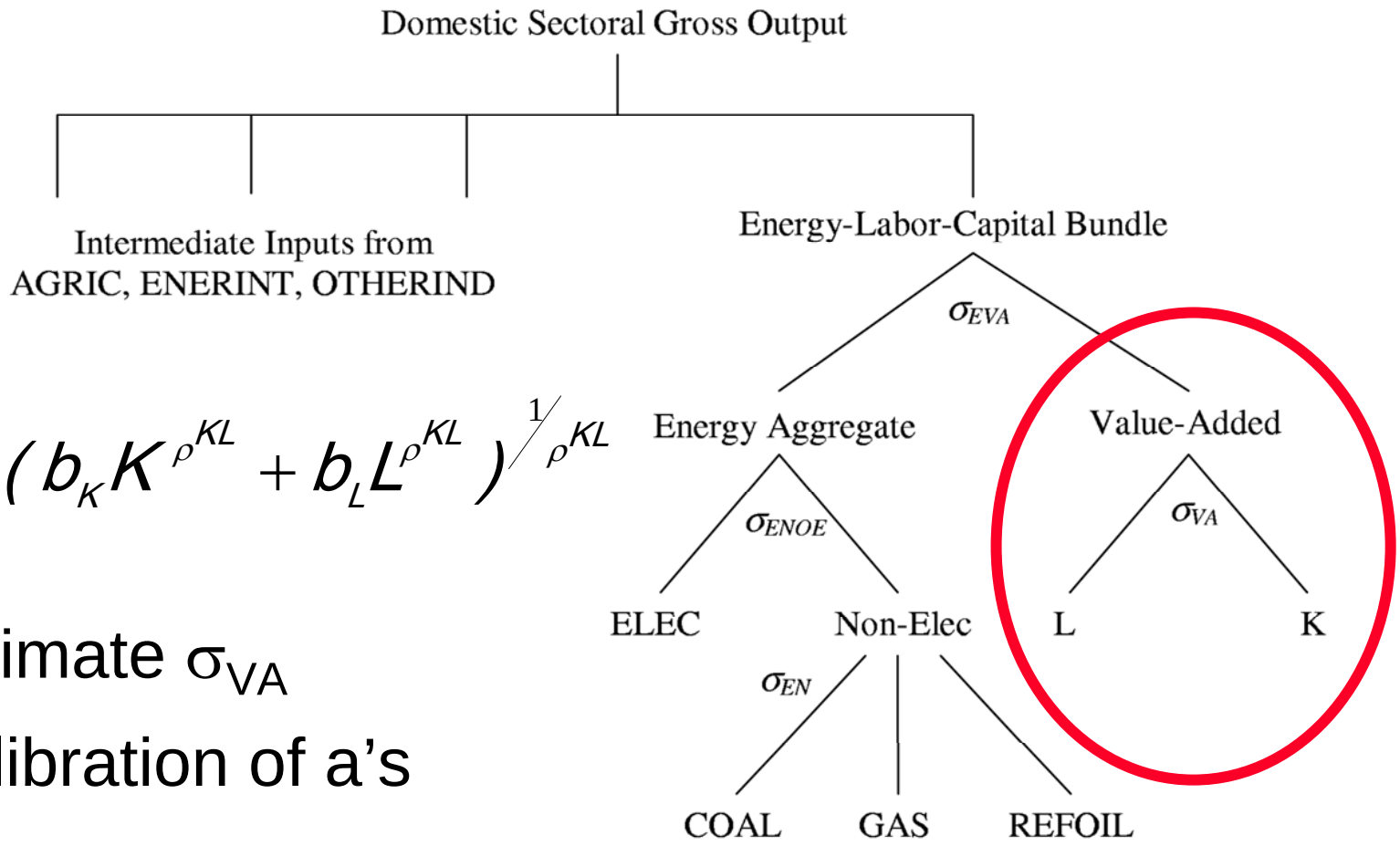
Energy
- Crude & Refined oil,
- Biofuel
- Shale oil
- Coal
- Natural gas
- Synthetic gas (from coal)
- Electricity

For special studies
Crude sources & gasoline, diesel, petcoke heavy oil, biodiesel, ethanol, NGLs & explicit upgrading

For special studies
Crops
Livestock
Forestry
Food processing

Technologies Included
Fossil (oil, gas & coal)
IGCC with capture
NGCC with capture
NGCC without capture
Nuclear
Hydro
Wind and solar
Biomass

Sample Production Structure



$$VA_t = a_t\left(b_K K^{\rho^{KL}} + b_L L^{\rho^{KL}}\right)^{1/\rho^{KL}}$$

Estimate σ_{VA}

Calibration of a's

The Base-Year Data
Social Accounting Matrix (SAM)

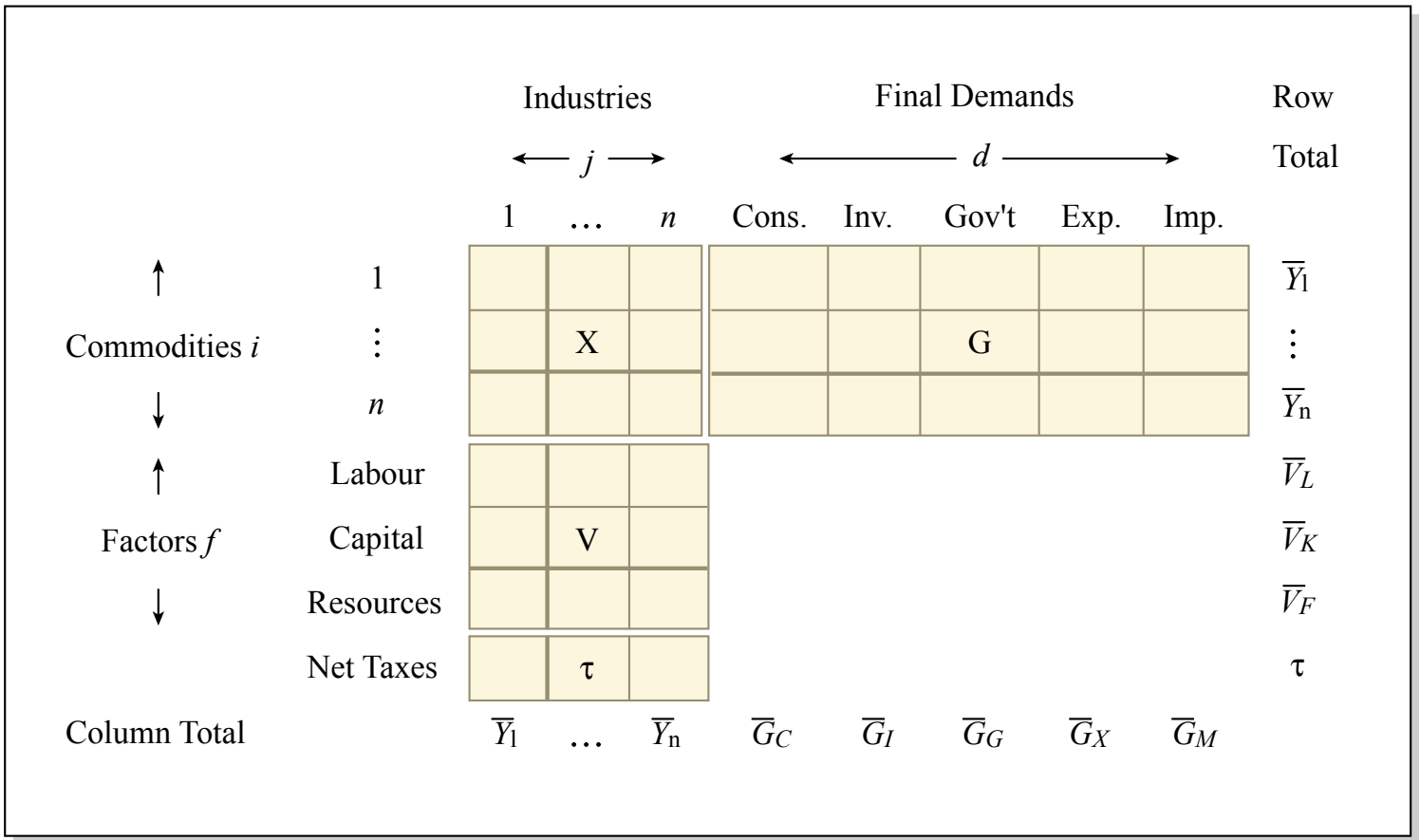
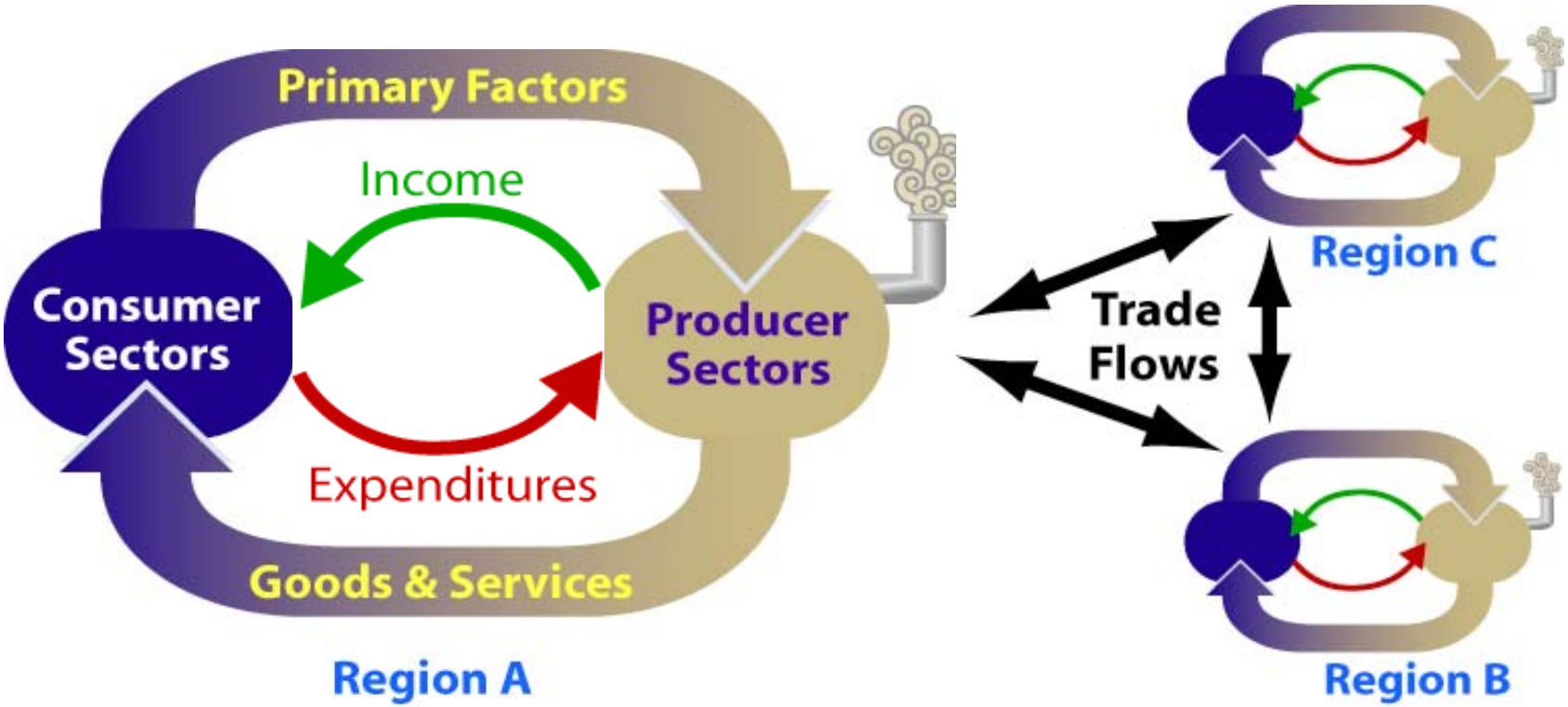


Figure by MIT OpenCourseWare.

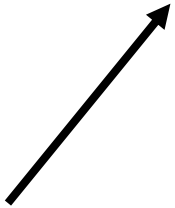
MIT (EPPA) Model
Multi-Regions and Trade



EPPA: Regional Aggregation

Annex B

- **USA**
- **Europe**
- **Canada**
- **Mexico**
- **Japan**
- **Aus. & N.Z.**
- **FSU**
- **E. Europe**



For special studies:

- Finland
- France
- Germany
- Britain
- Italy
- Holland
- Spain
- Sweden
- Hungary
- Poland
- Other

Non-Annex B

- **China**
- **India**
- **Persian Gulf**
- **Indonesia**
- **Africa**
- **Latin America**
- **East Asia**
- **Rest of World**

Scenarios of Emissions & Concentrations

The three models (U.S. CCSP pp. 47-48)

Feature	IGSM/EPPA	MERGE	MiniCAM
Structure	General equilibrium	General equilibrium	Partial equilibrium
Solution	Recursive dynamic	Forward looking	Recursive dynamic
Population	Exogenous	Exogenous	Exogenous
Labor force	Proportional to population	Proportional to population	Population demographics
Main growth driver	Exog. Labor productivity	Exog. Labor productivity	Exog. Labor productivity
Structure of final demand	Sectors shown earlier	Single prod'n sector (GDP)	Buildings, transport, industry

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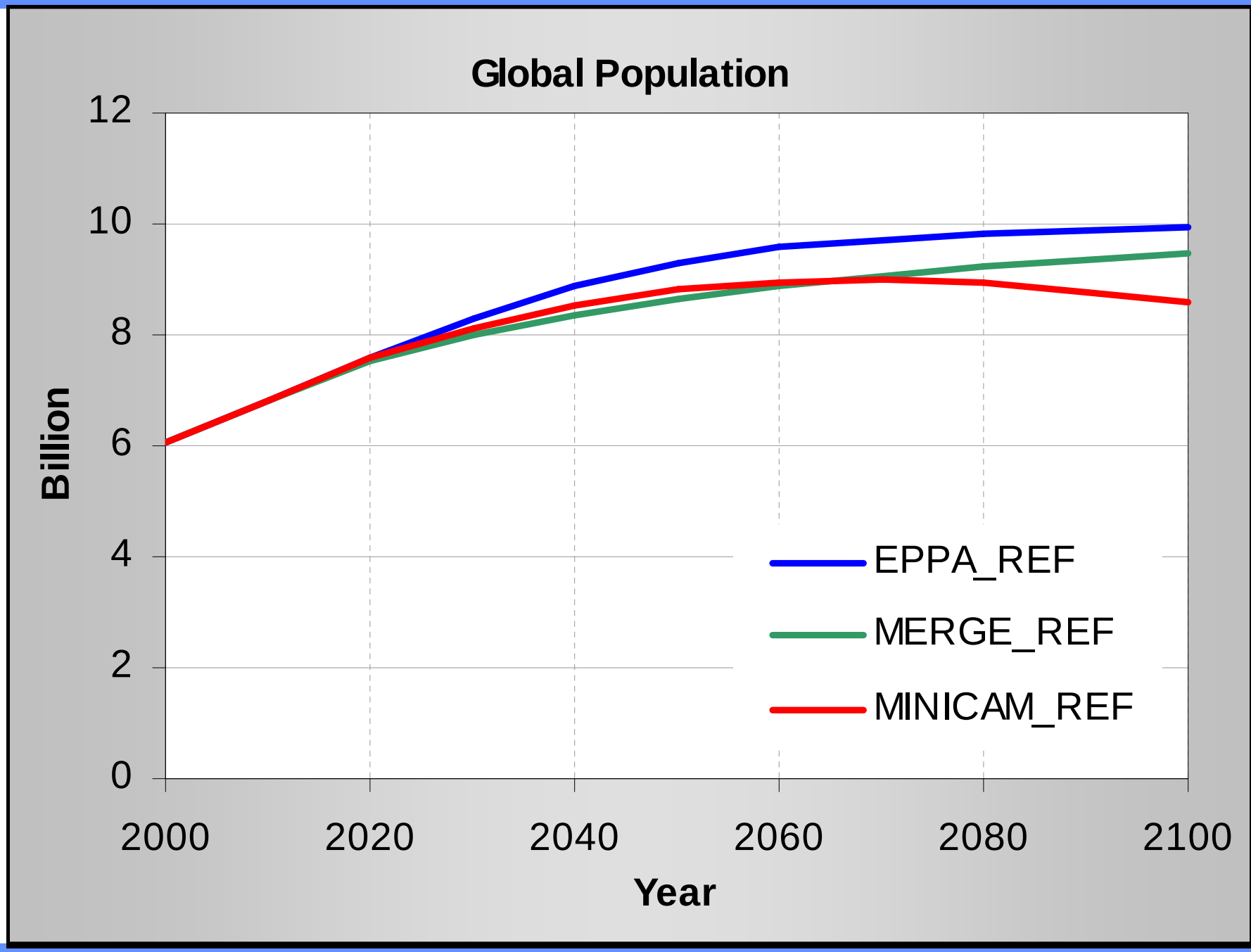
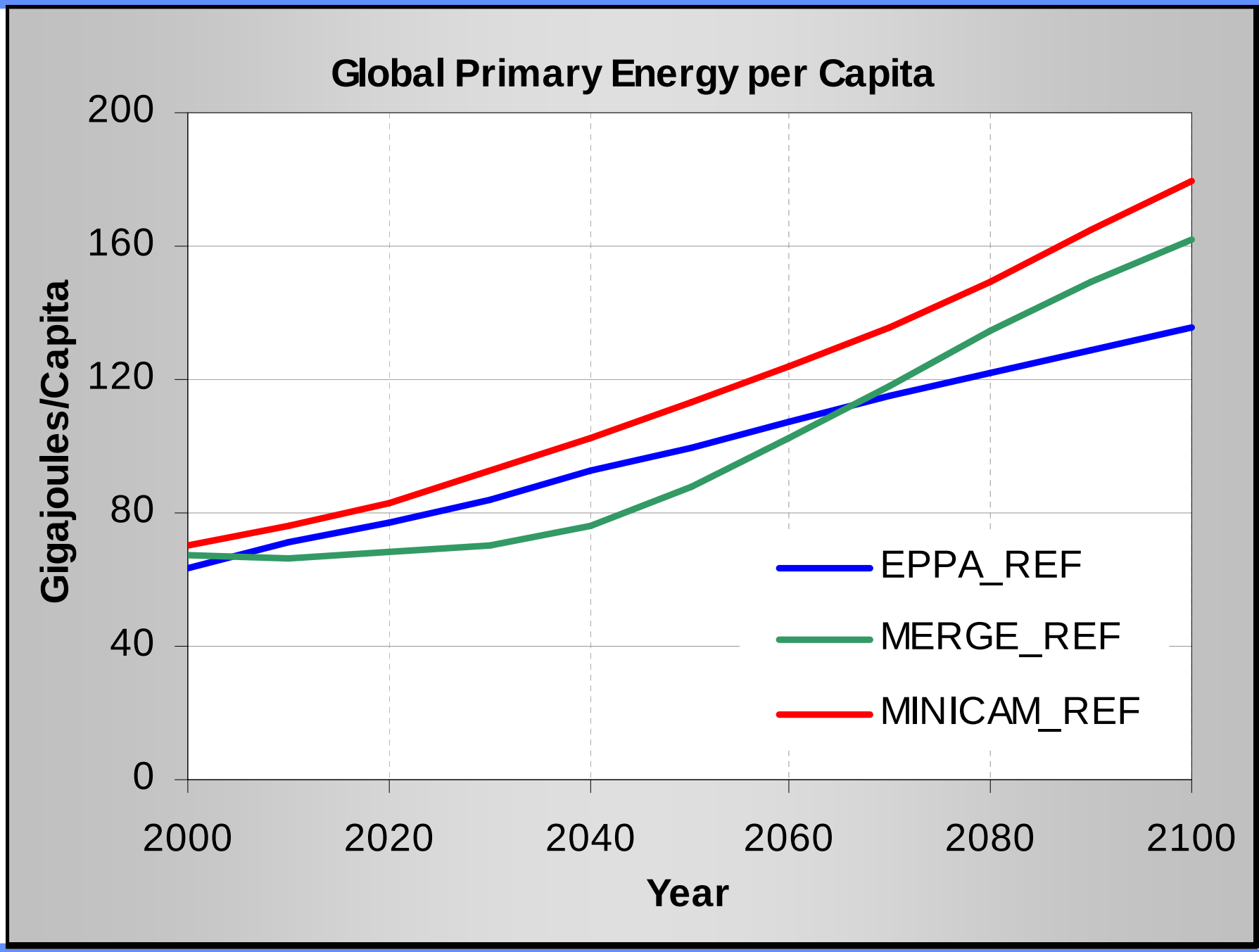
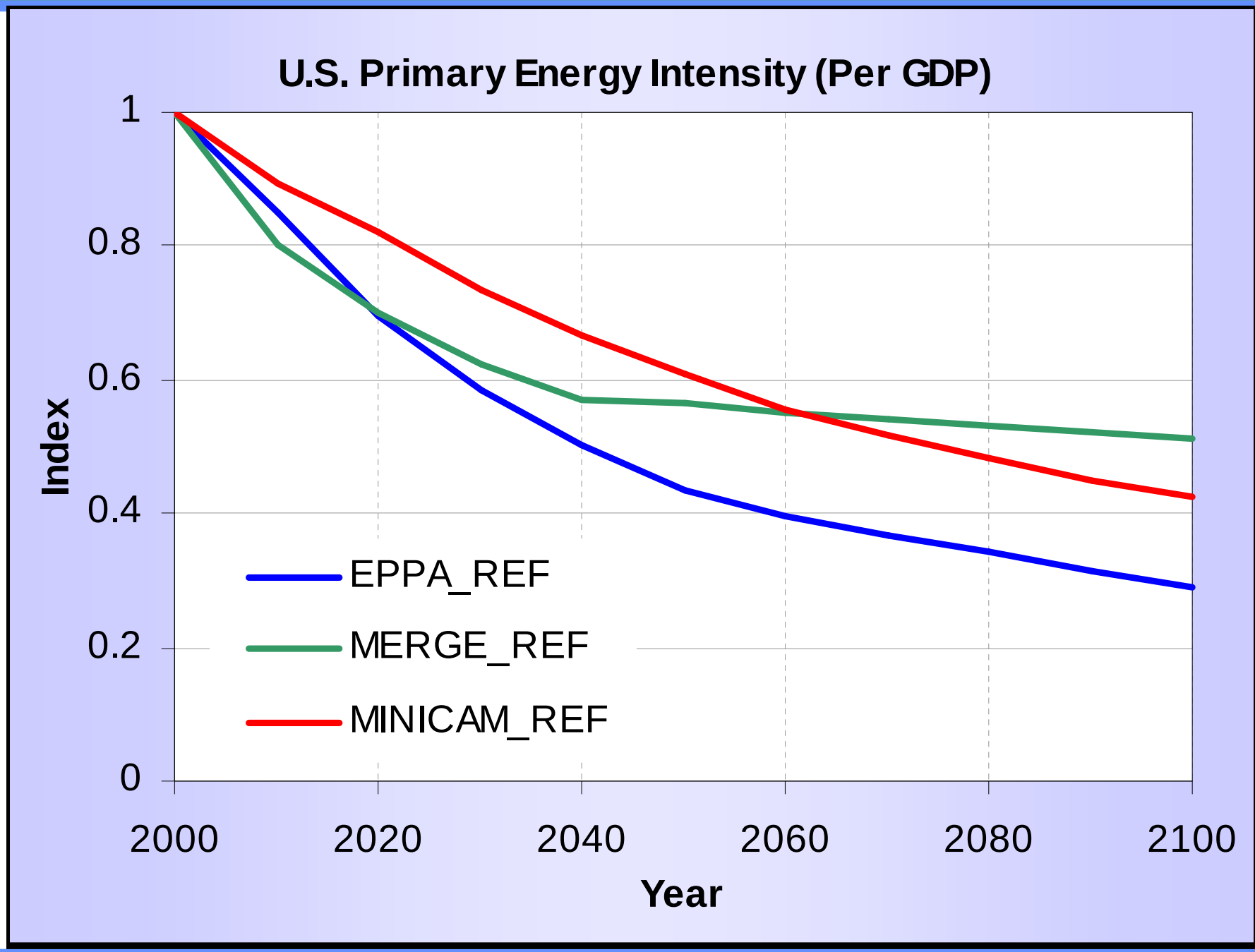
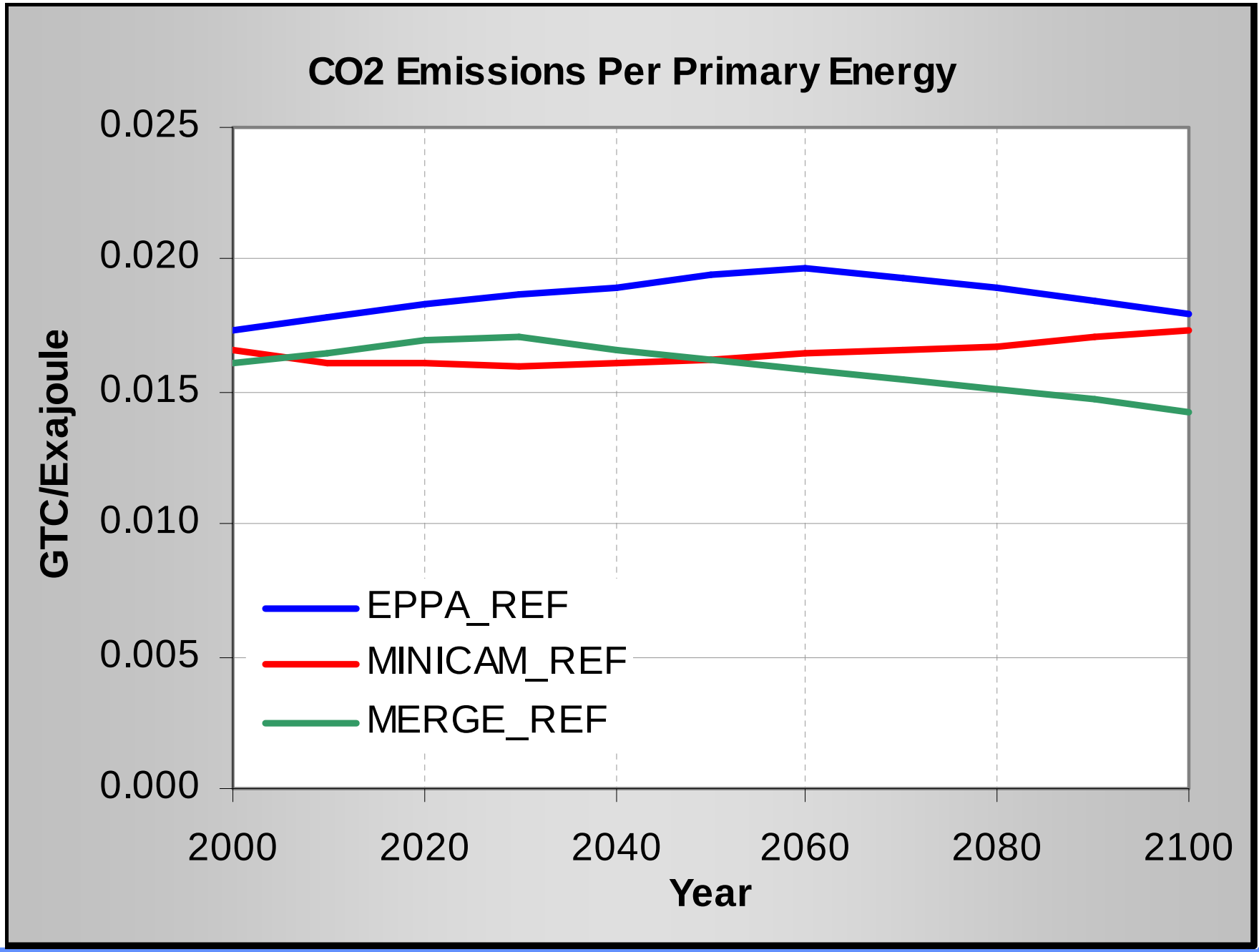
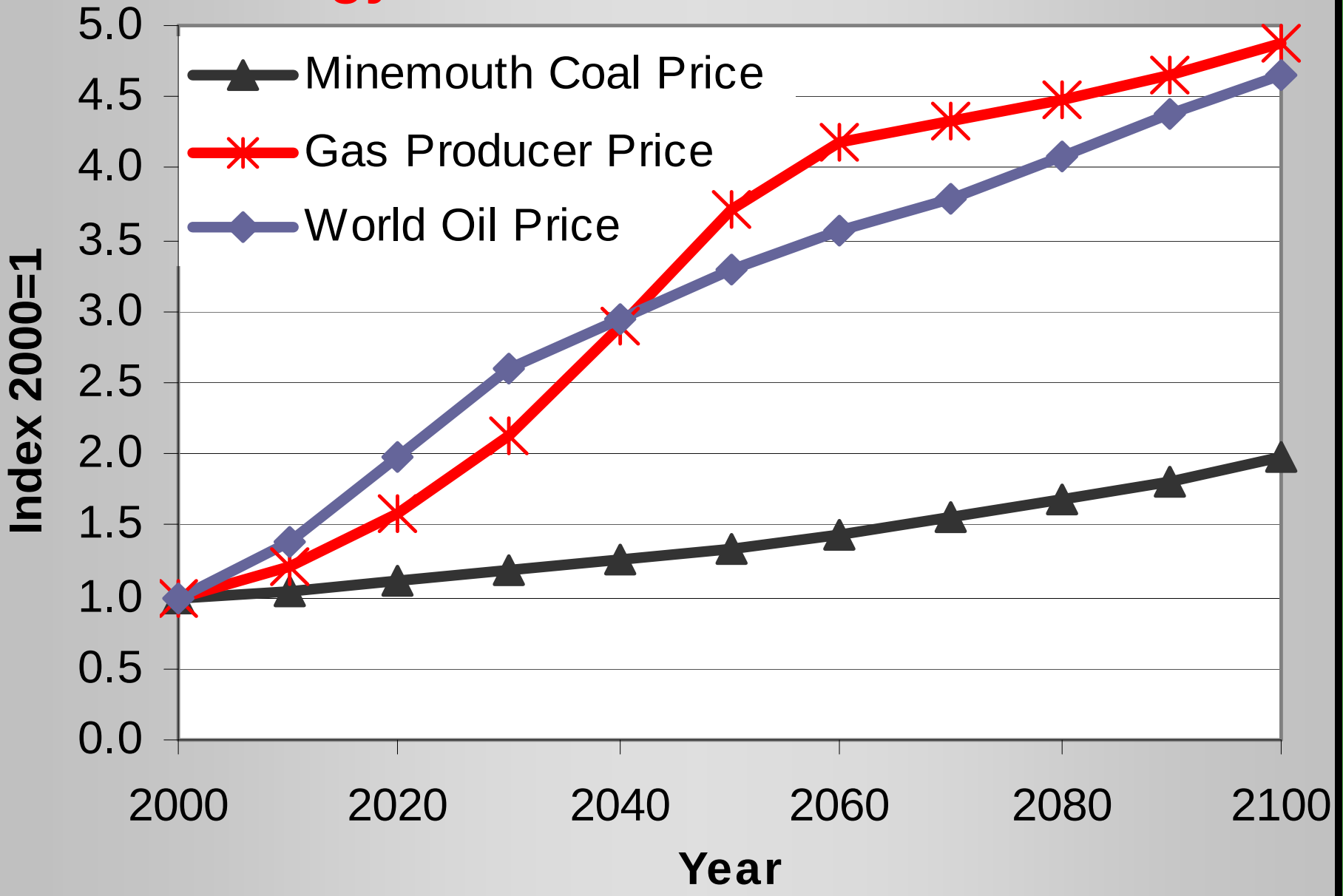

Global Population
12
10
8
6
4
2
0
Billion
2000
2020
2040
2060
2080
2100
Year
EPPA_REF
MERGE_REF
MINICAM_REF


Global Primary Energy per Capita
200
160
120
80
40
0
Gigajoules/Capita
2000
2020
2040
2060
2080
2100
Year
EPPA_REF
MERGE_REF
MINICAM_REF

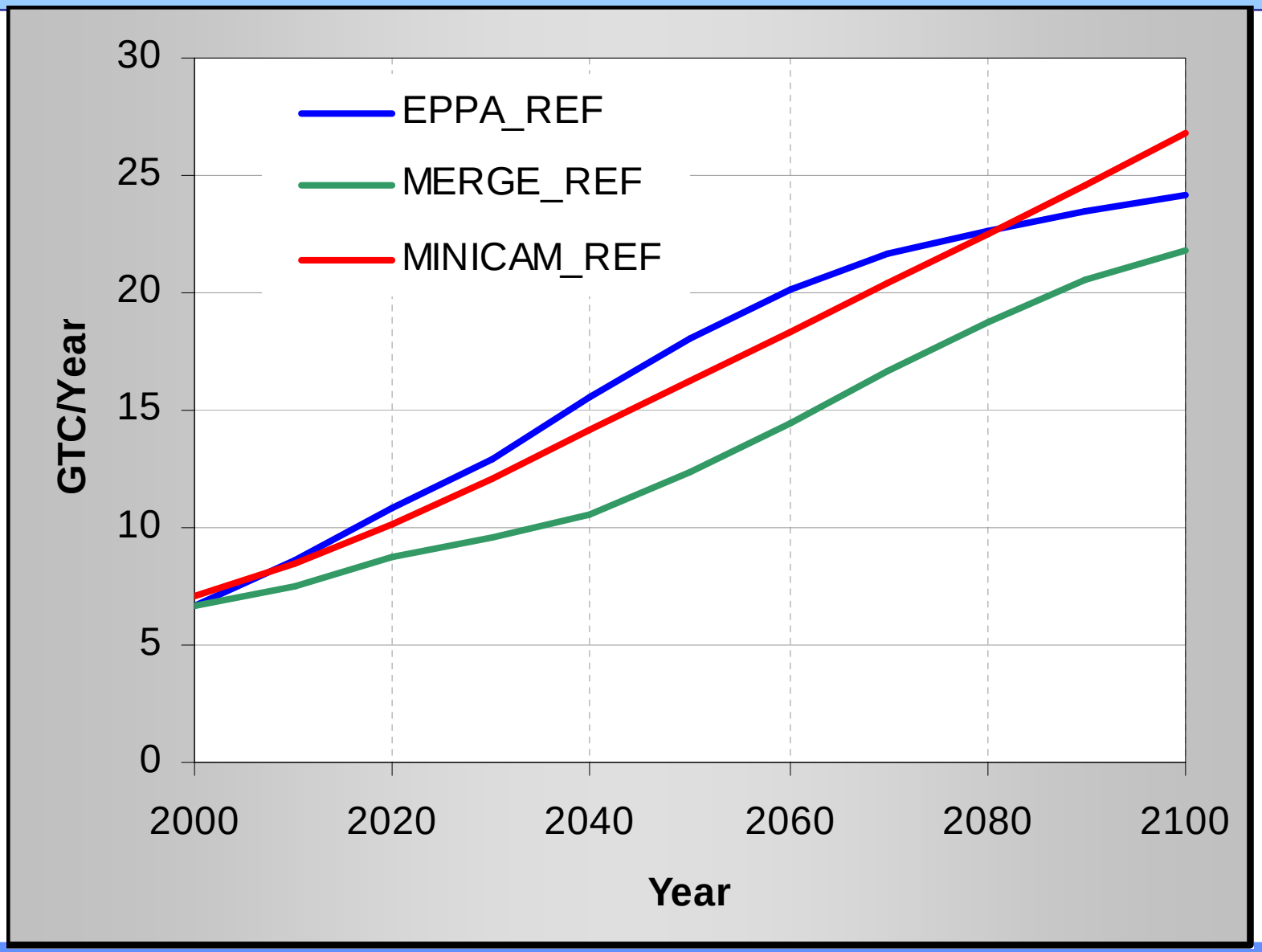

U.S. Primary Energy Intensity (Per GDP)
Index
1
0.8
0.6
0.4
0.2
0
2000
2020
2040
2060
2080
2100
Year
EPPA_REF
MERGE_REF
MINICAM_REF


CO2 Emissions Per Primary Energy
GTC/Exajoule
0.025
0.020
0.015
0.010
0.005
0.000
2000
2020
2040
2060
2080
2100
Year
EPPA_REF
MINICAM_REF
MERGE_REF

Energy Prices: Reference Scenario



Global Industrial CO_2 Emissions



Global Primary Energy: Reference