Energy Development Strategy for China with Application of MARKAL

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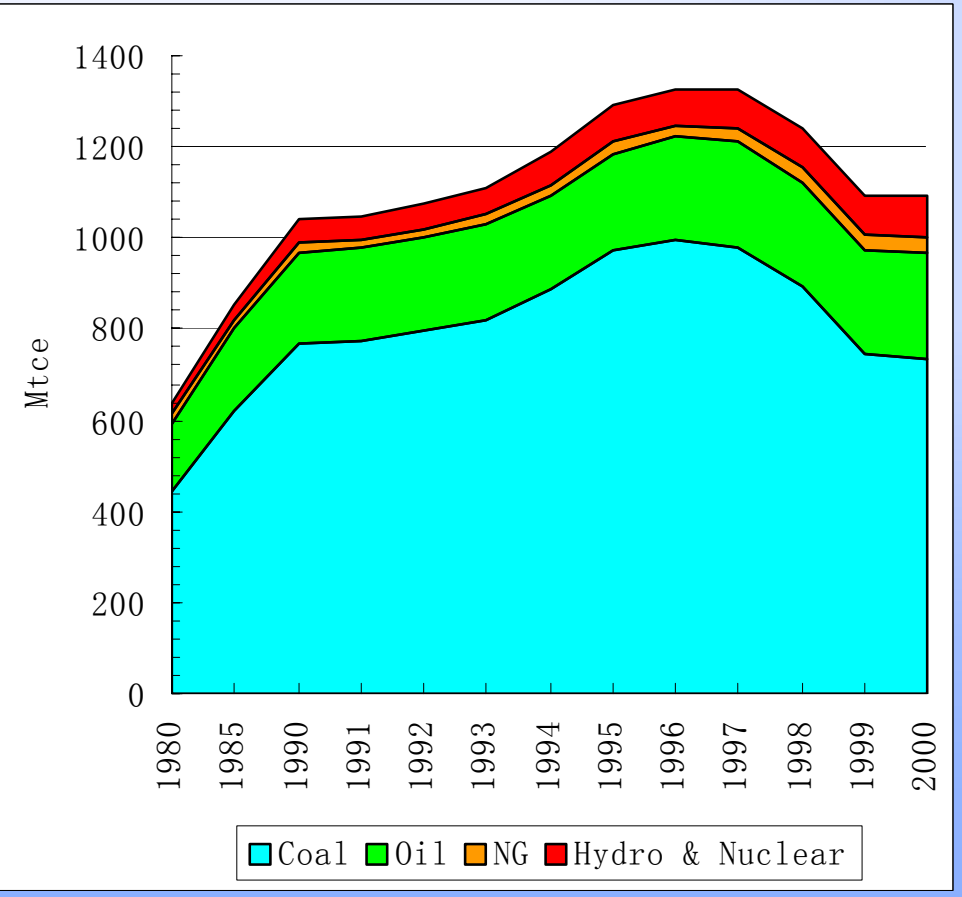
Topics of discussion

- Current status of China energy
- Challenges for China energy in the new century
- Modeling approach for future energy development strateg
- Energy service demand projection and modeling results fo transportation sector
- Modeling results for whole China
- Conclusions

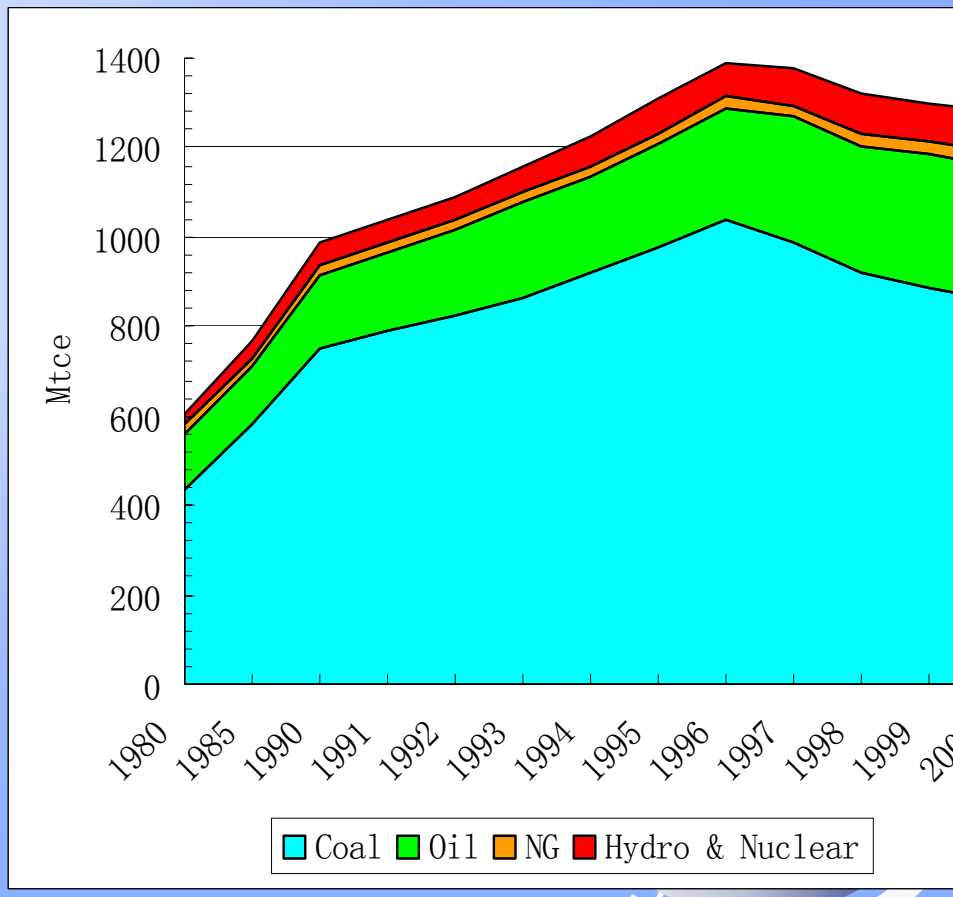
Current status of China Energy

Primary energy production and consumption

Production



Consumption

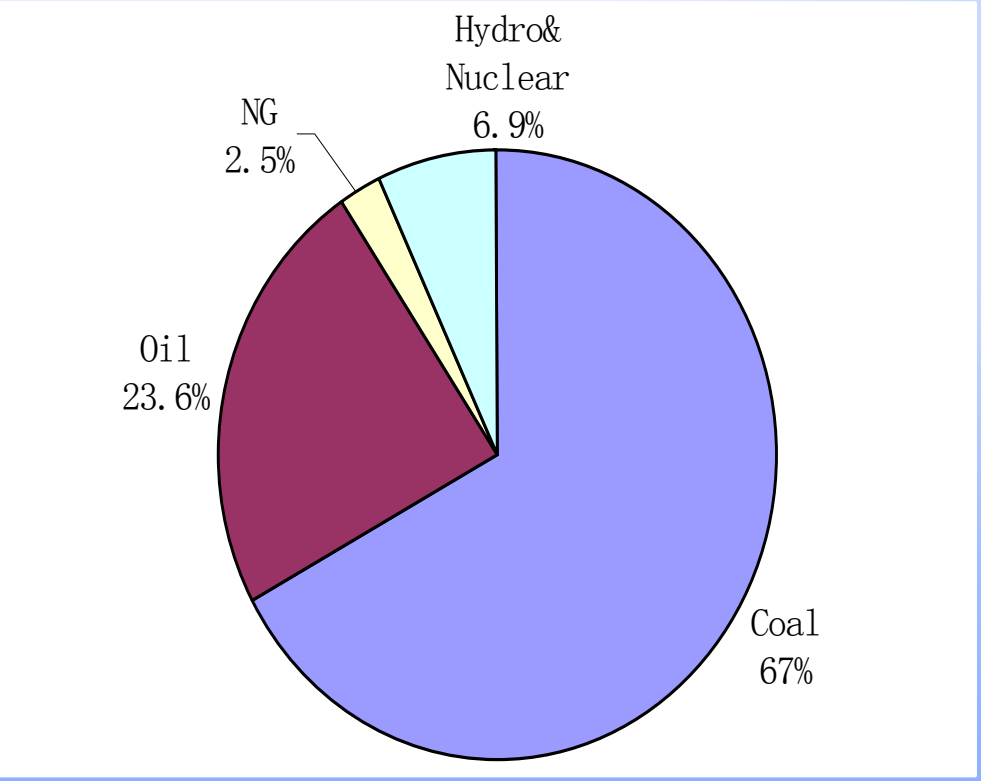


Reasons for the reduction of primary energy consumption

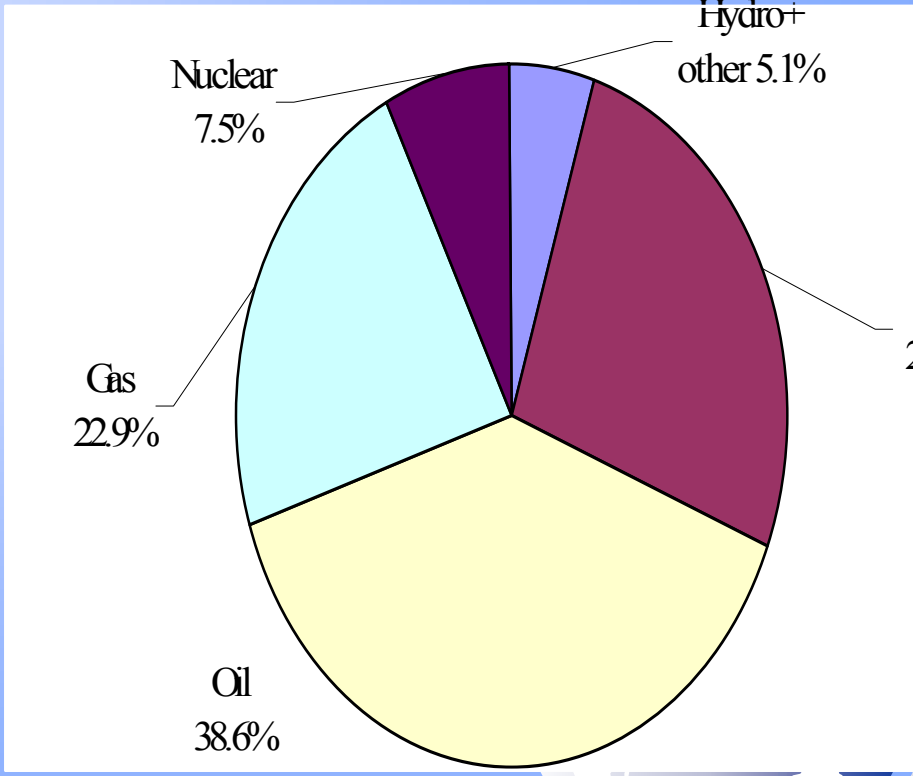
- Chinese government's policy to restrict and to wash out production of coal with high ash and sulfur content, and to close small coal mines, conduced great reduction of coal output while improvement of coal quality.
- Energy efficiency improvement caused by more use of "good" energy.
- A large amount of small enterprises with high energy intensity were washed out or reorganized, resulting to the decline of fully energy consumption per unit industrial output.
- Natural growth rate of population declined continually. It dropped to 1% in 1997 and fell further to 0.877% in 1999.
- Annual GDP growth rate during 1990-1996 was 11.6%, but it dropped to 7.77% during 1997-2000.
- Statistical error.

Comparison of fuel mix for primary energy consumption

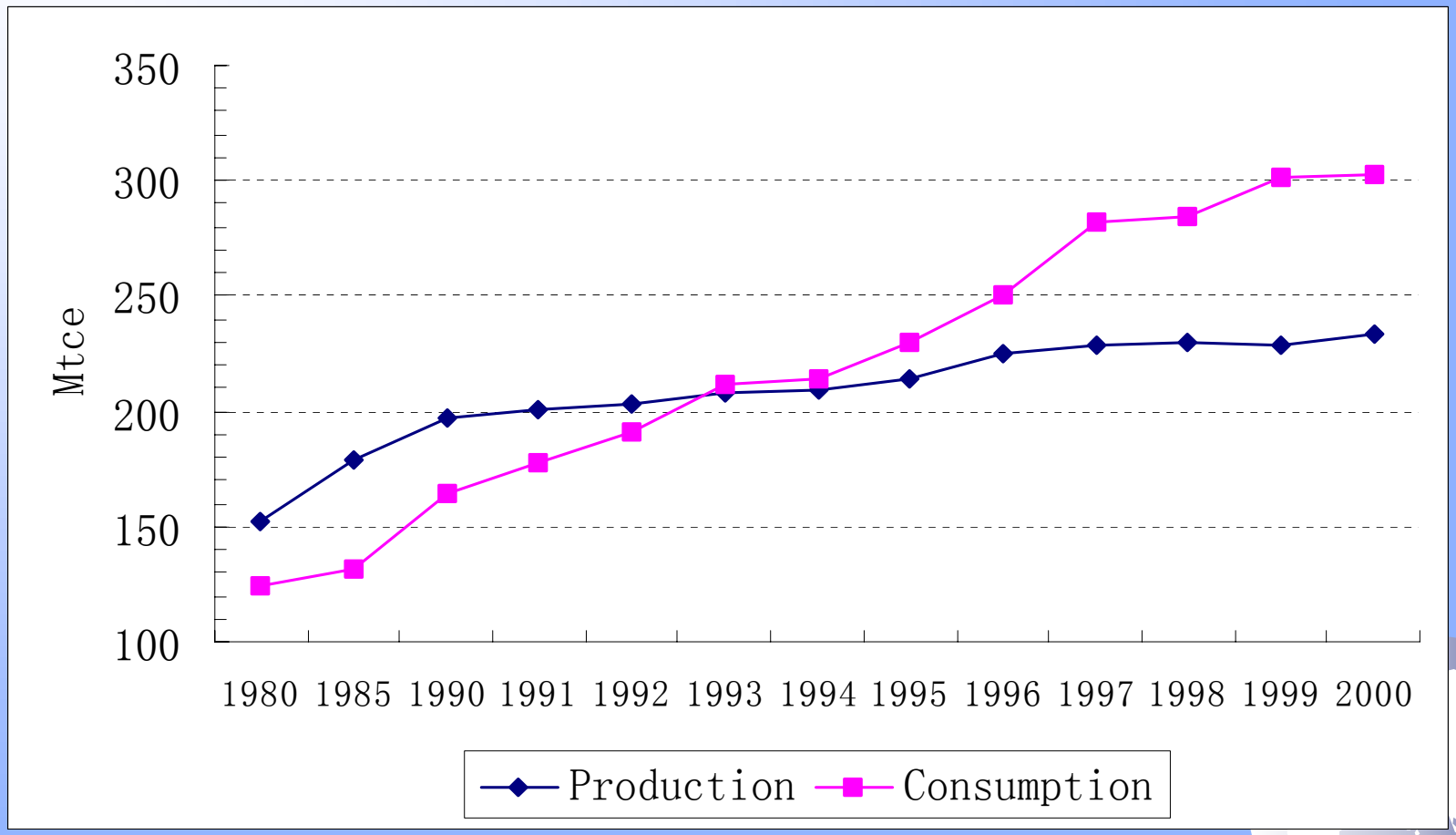
China



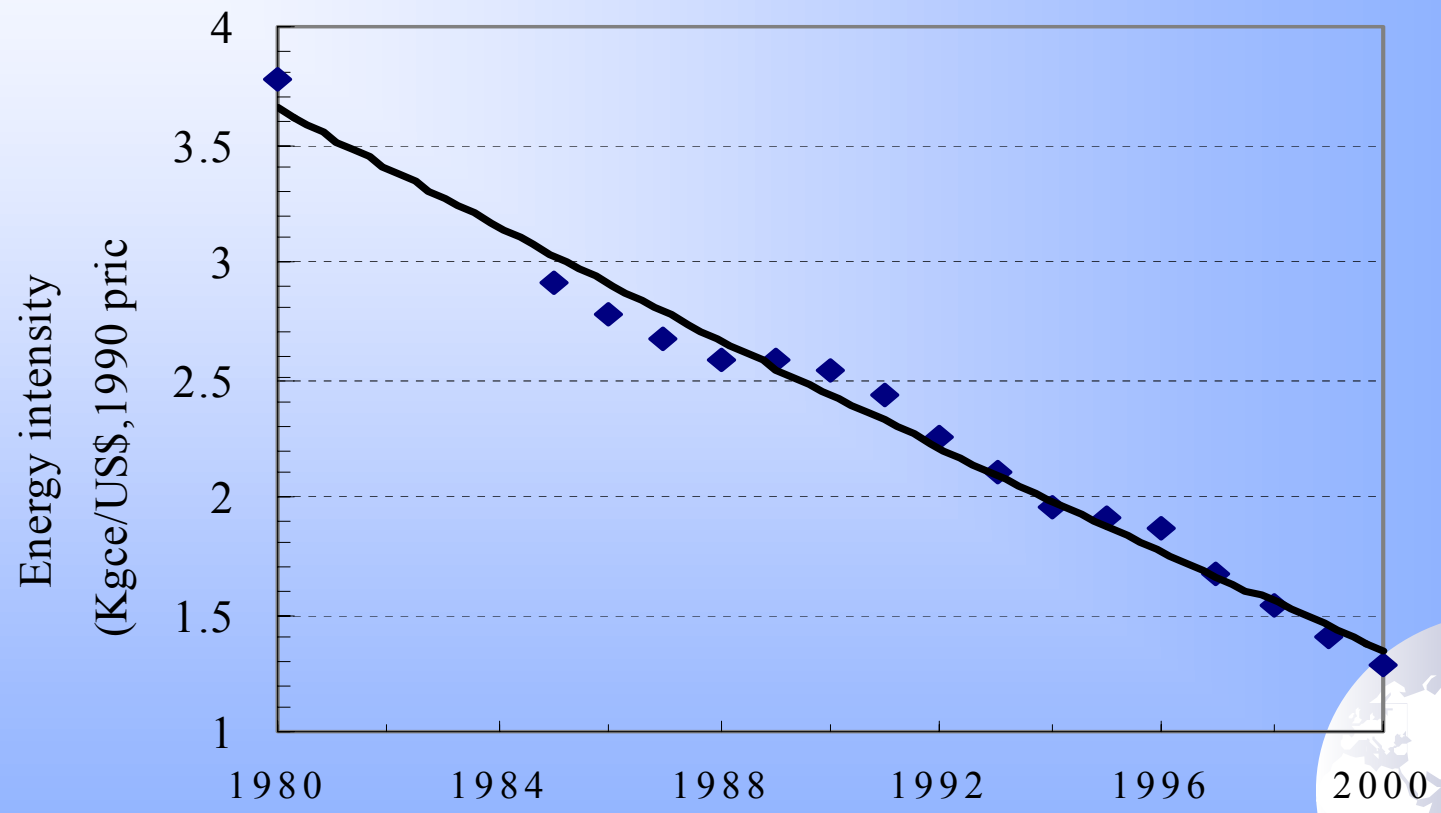
World



Oil supply and demand



Energy intensity



Challenges for China energy in the new century

Energy sector structural adjustment

- Excessively high coal utilization
- Insufficient gas and new and renewable energy

Energy security

- Demand for oil is expected to experience dramatic increase due to continued boost of transport sector, especially significant growth of car ownership
- Limited domestic oil resources

Local environment protection

- Increasingly severe air pollution
  - In 2000, Chinese cities' annual average concentration of SO_2 was 49μg/m^3, NOx 37μg/m^3 and TSP 271μg/m^3, while the national second grade standard for SO_2, NOx and TSP are 60μg/m^3, 50μg/m^3 and 200μg/m^3 respectively.
- Mainly attributable to direct coal combustion

Global climate change

- Second largest CO_2 emitting nation in the world.
- China is up against heavier and heavier pressure such as "voluntary commitment of GHG reduction" from the developed countries in international negotiation on global climate change issue.

Modeling approach for future energy development strategy

---Integrated Energy, Environment model, Markal

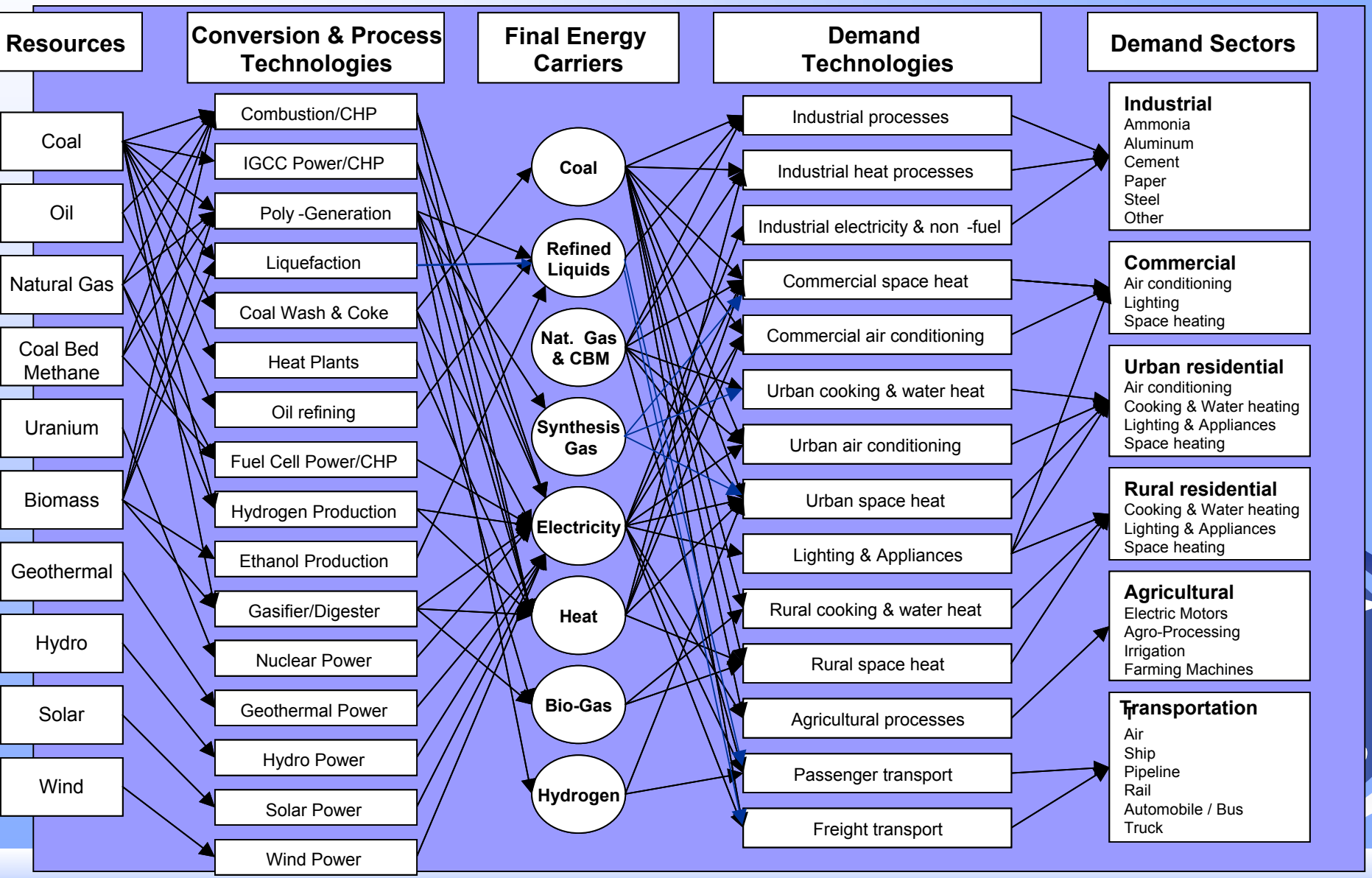
Brief description of MARKAL Model

- MARKAL is a dynamic linear programming model based on Reference Energy System(RES).
- Incorporates the full range of energy processes e.g. exploitation, conversion, transmission, distribution and end-use.
- Considers existing technologies as well as advanced technologies which may be deployed in future.
- The objective function is to minimize energy system cost, including the capital costs of end-use (demand) technologies, capital costs of electricity generating technologies, fuel costs, infrastructure costs (such as pipelines), and operating and maintenance costs.

Main constrain Equations in Markal

- Balance equation for energy carriers
- Base-load electric equation
- Electric peaking equation
- Heat peaking equation
- Capacity transfer equation(for conversion technologies, process technologies, end-use technologies respectively)
- Capacity/activity equations (for electricity generation, heating plant, process technologies respectively)
- Demand equation
- Cumulative resource availability
- Emissions
- User-defined equations
- Etc.

Simplified RES for China Markal



Technologies: Conversion(Electricity)

- E01: Coal-fired, 100MW and less
- E02: Coal-fired, 100-200MW
- E03: Coal-fired, 200-300MW with ESP
- E04: Coal-fired, 300MW and above with ESP
- E05: Coal-fired, 300MW and above with ESP and dry FGD
- E06: Coal-fired, 300MW and above with ESP and wet FGD
- E07: Coal-fired, 300MW and above with ESP and combined SOx/NOx removal scrubber
- E08: AFBC
- E09: PFBC
- E0A: IGCC
- E0B: Co-generation
- E0C: Super critical
- E0D: Ultra super critical
- E11: oil-fired traditional plant
- E12: oil-fired combined cycle plant
- E21: conventional gas turbine combined cycle plant
- E22: advanced gas turbine combined cycle plant
- E31: nuclear power generation
- E41: hydropower station
- E51: photovoltaic power station
- E61: geothermal power
- E71: wind power generation
- ……

Technologies: Process

- PCW: coal washing
- PCK: coke making
- PCL: coal liquefaction
- PCG: coal gasification
- PCH: hydrogen making
- POR: oil refinery
- ……

Technologies : Demand(Industry)

- IS1: Steel (existing)
- IS2: Steel (advanced)

- IM1: Ammonia (using coal as raw material)
- IM2: Ammonia (using oil as raw material)
- IM3: Ammonia (using gas as raw material)

- IL1: Aluminum (existing)
- IL2: Aluminum (advanced)

- IC1: Cement (wet)
- IC2: Cement (dry)
- IC3: Cement (small)

- IP1 :Paper (existing)
- 1P2: Paper (advanced)

Technologies: Demand(Commercial)

- Space heating and water heating
  - District heating
  - Coal-fired centralized boiler
  - Coal-fired scatter boiler
  - Oil-fired boiler
  - Gas-fired boiler
  - Heat pump
  - Gas burner
  - Oil burner
  - Coal-fired centralized boiler + absorption chiller
  - Gas-fired boiler+absorption chiller
  - Oil-fired boiler+absorption chiller
- Cooling
  - Electric chiller
  - heat pump
  - Gas burner
  - Oil burner
  - Coal-fired centralized boiler + absorption chiller
  - Gas-fired boiler+absorption chille
  - Oil-fired boiler+absorption chiller

Technologies :Demand(Residential)

Urban

- Space heating
  - District heating
  - Coal-fired centralized boiler
  - Coal-fired scatter boiler
  - Oil-fired boiler
  - Gas-fired boiler
  - Heat pump
  - Coal stove
- Cooling
  - Room conditioner
  - Heat pump
- Cooking and water heating
  - Electric stove
  - Coal stove
  - NG stove
  - LPG stove

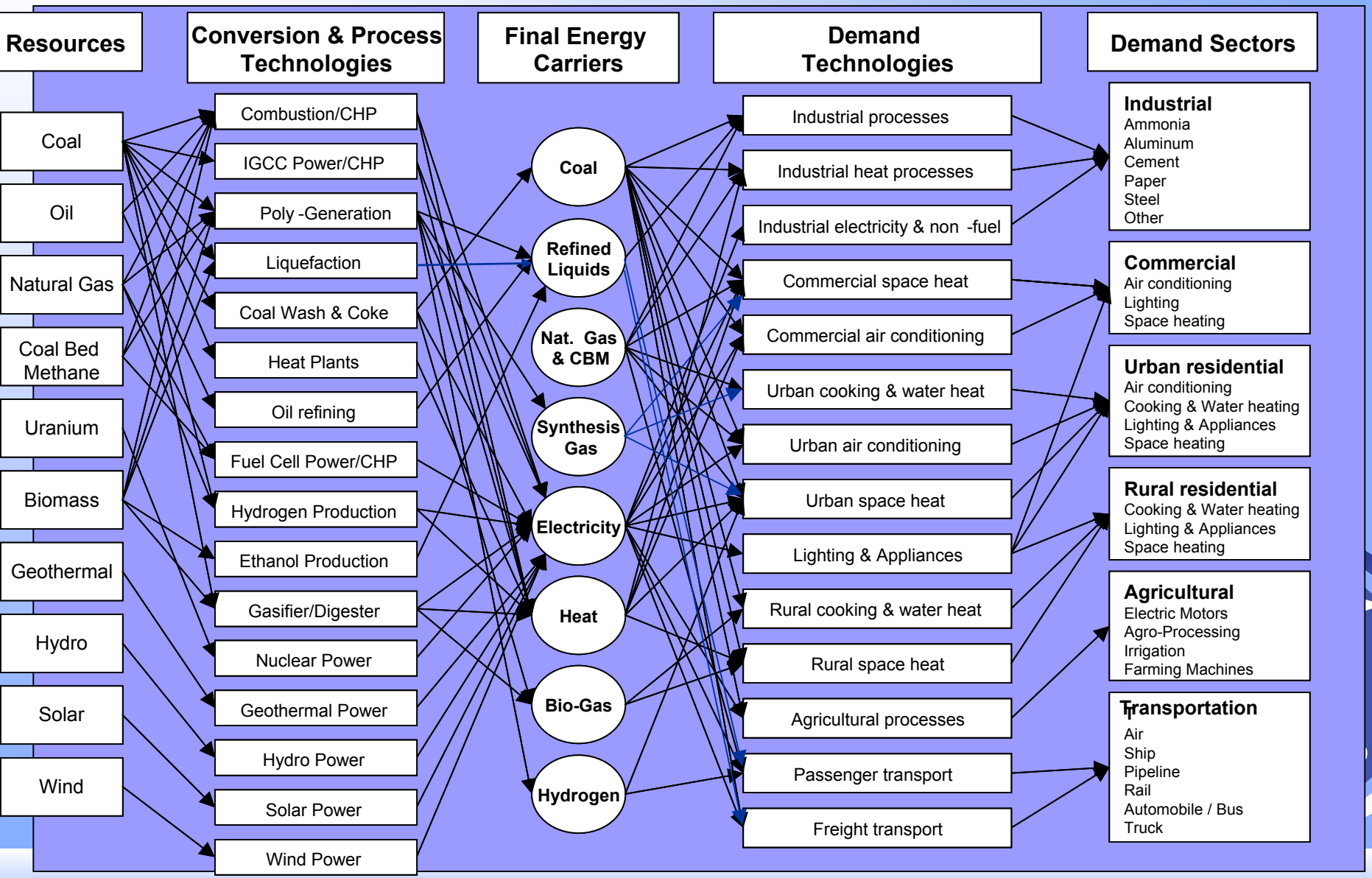
Rural

- Space heating
  - Coal stove
  - Solar house
  - Biomass stove
- Cooking and water heating
  - Coal stove
  - Biomass stove
  - Biogas stove
  - Solar stove
  - LPG stove
  - NG stove
  - Electric stove

Technologies : Demand(Transportation)

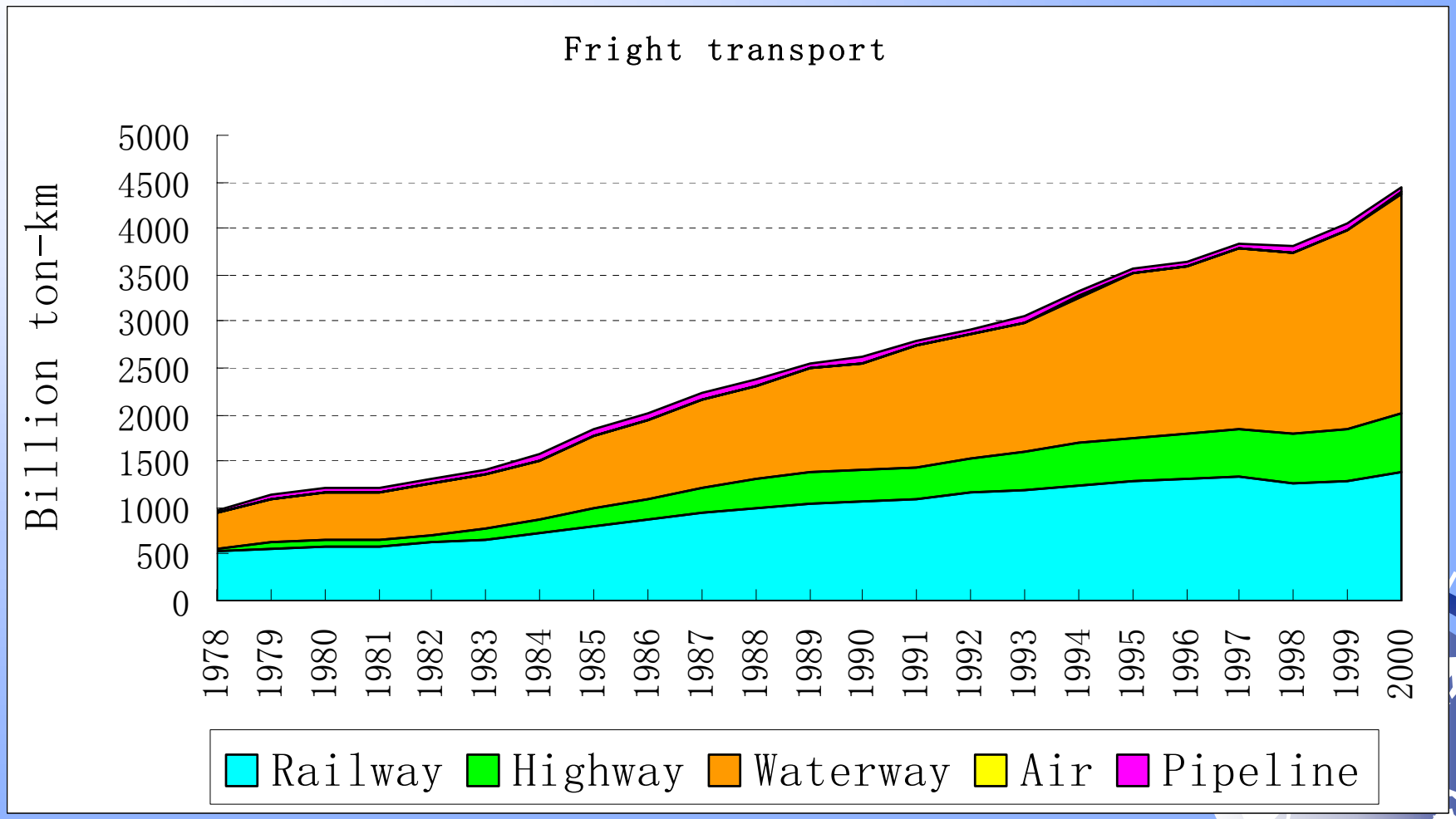
- Railway
  - Steam locomotive
  - Diesel locomotive
  - Electric locomotive
- Truck
  - Gasoline
  - Diesel
  - CNG
  - LPG
  - Fuel cell
  - DME
  - Methanol + diesel
  - …
- Automobile
  - Gasoline
  - CNG
  - Electric
  - Fuel cell
  - DME
  - …
- Ship
  - Diesel
  - Fuel oil
- Pipeline
  - Fuel oil, electricity
- Air
  - Jet fuel

Simplified RES for China Markal



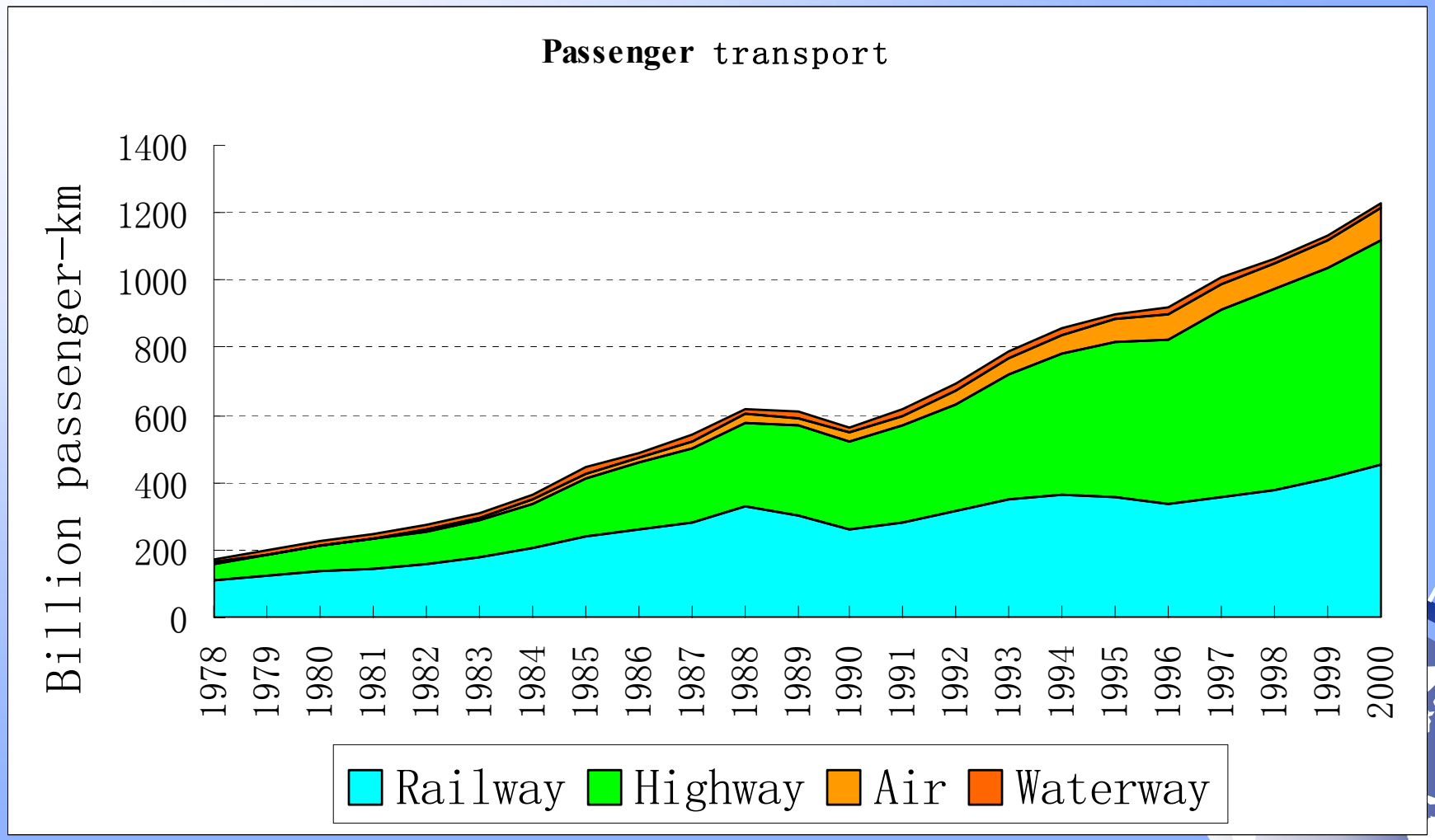
Energy service demand projection and modeling results for transportation sector

Historical trend for freight transport



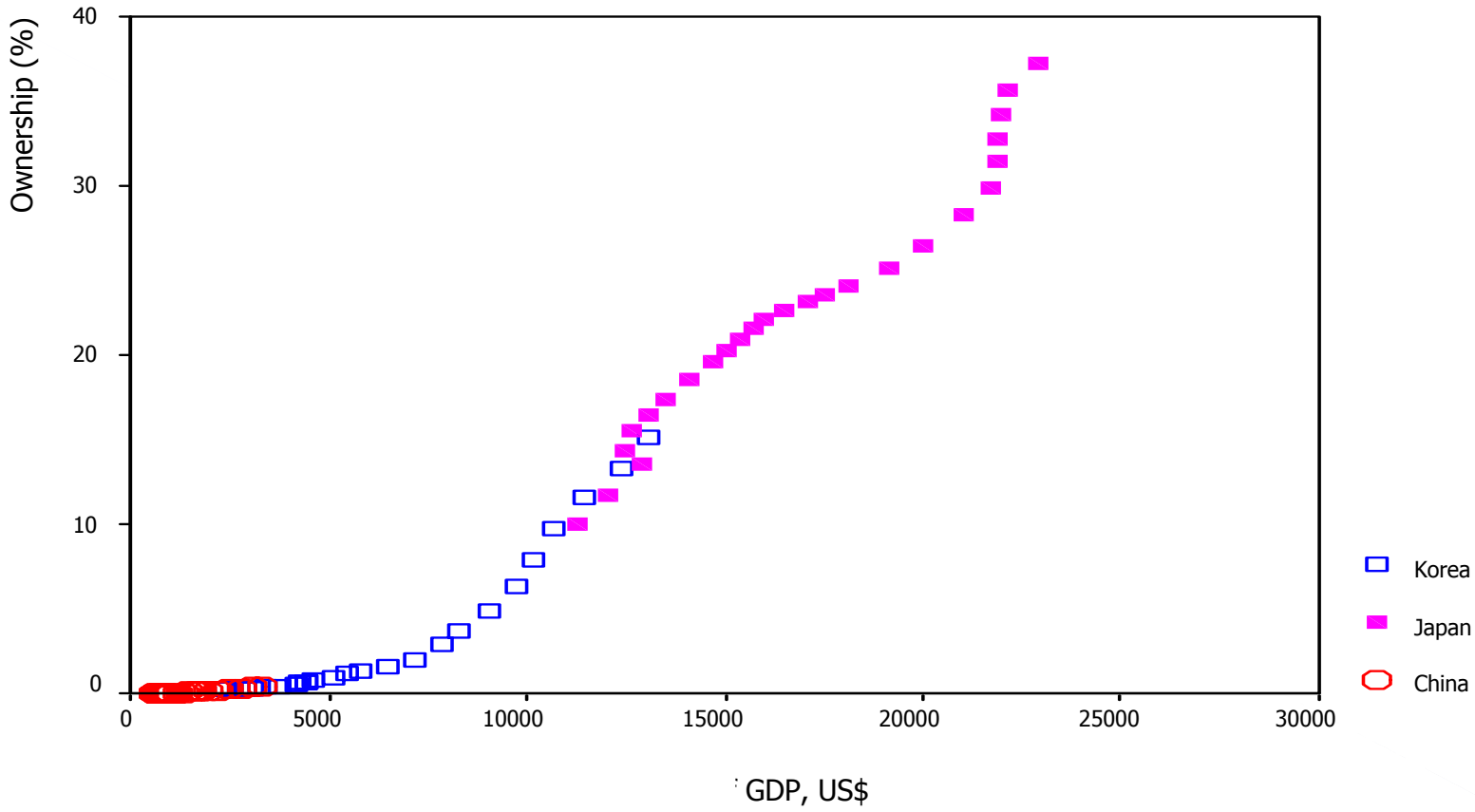
	1978	2000		1978	2000
Railway	54%	31%	Highway	2.7%	13.7%

Historical trend for passenger transport



	1978	2000		1978	2000
Railway	62%	36%	Highway	29%	54%

Car ownership for China, Korea and Japan



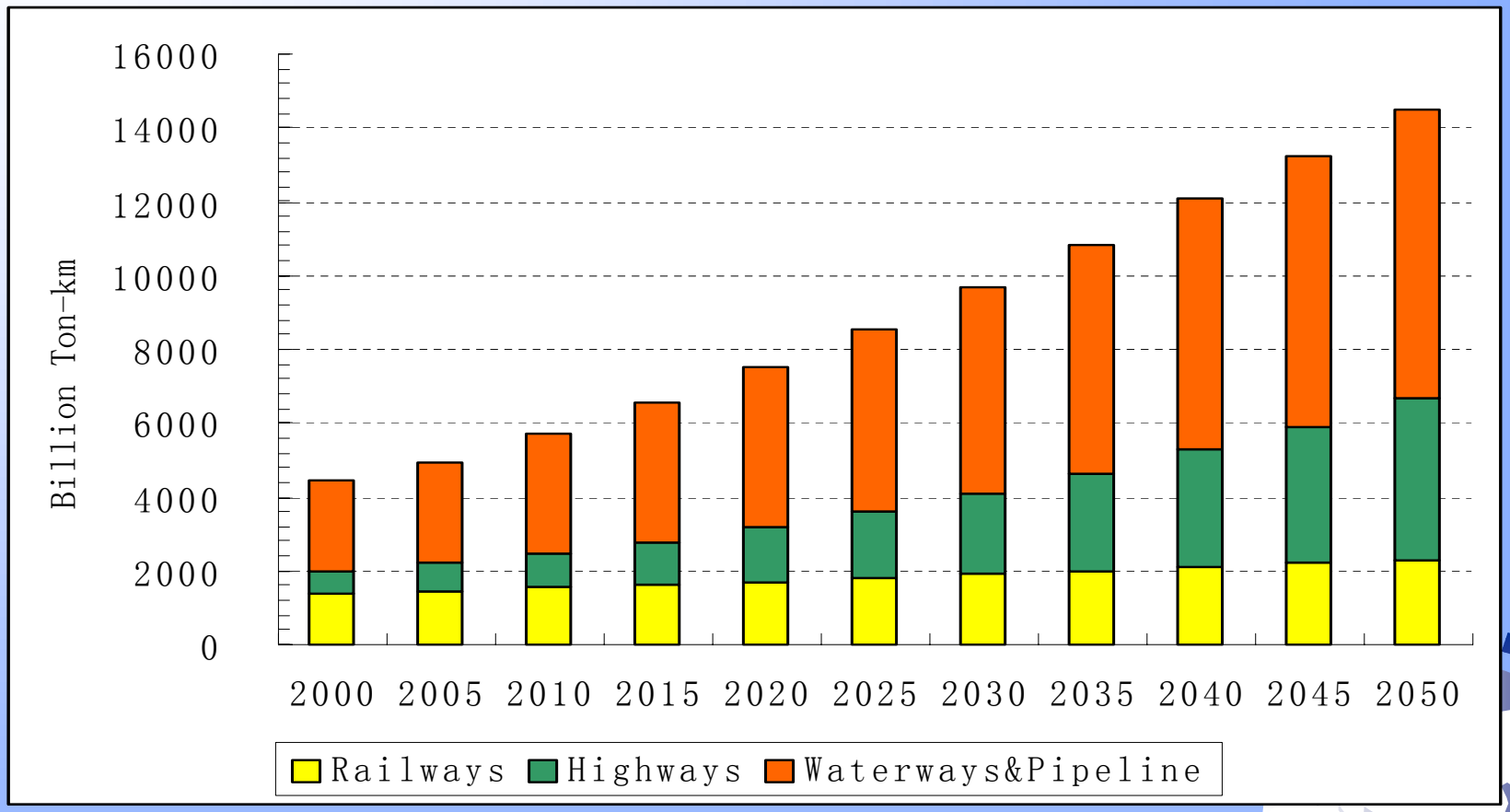
Projection formula for Freight ton-km

- Total
  - FRT.T= -6412.010+0.381 * GDP+1469.786 * LN(GDP)
- Railways
  - LN(FRT.RL) = 0.56365 -0.28977 * LN(GDP.P)+ 1.03013 * LN(FRT.T);
- Highways
  - FRT.RD ==-1709.763+243.584* LN(FRT.T)+0.338*GDP.P;
- Ship&PIPELINE
  - FRT.SHIP&PIPELINE= FRT.T- FRT.RD- FRT.RL

Projection formula for Passenger-km

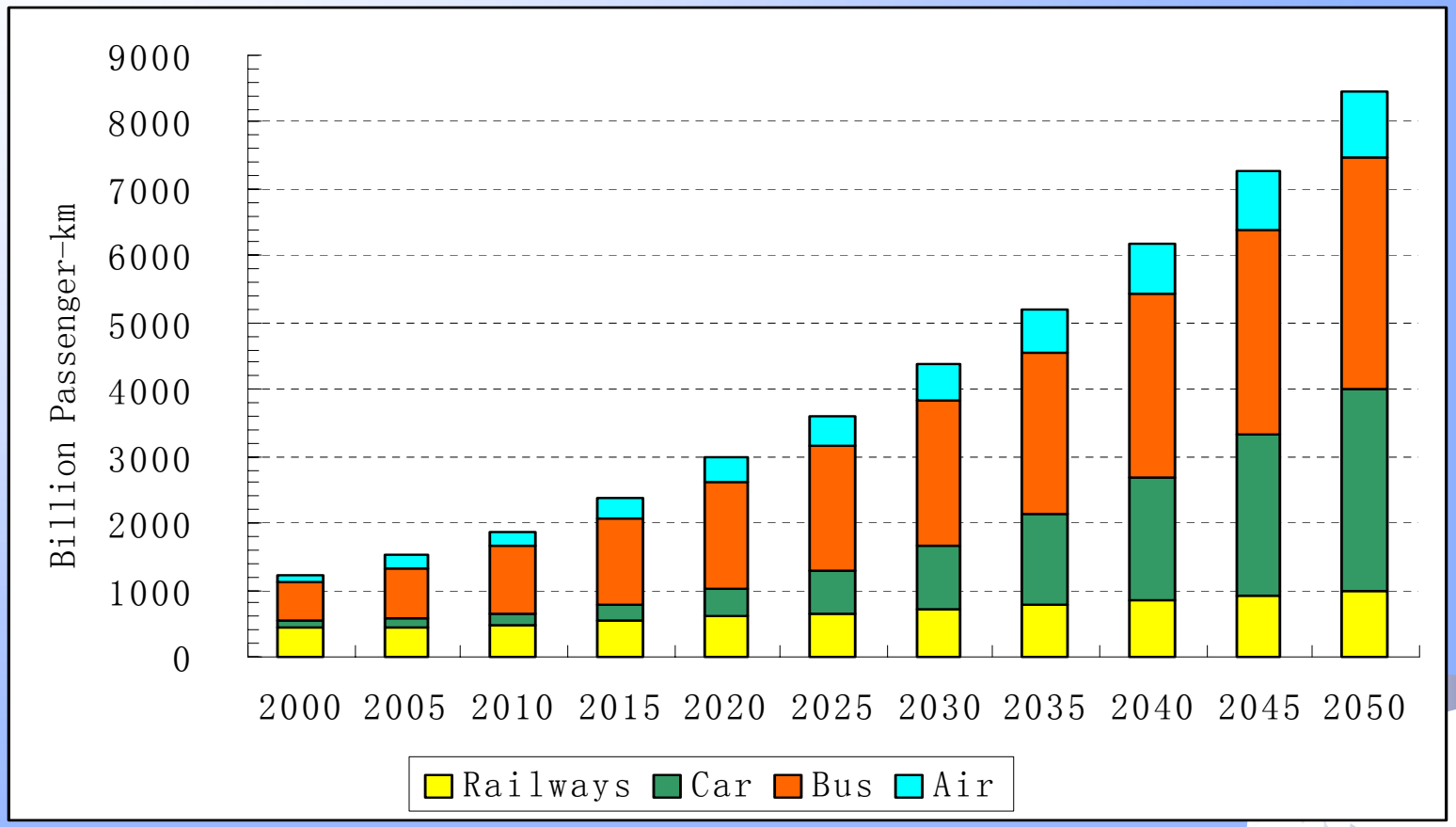
- **Total**
  - PAS.T= -1600.516 +0.624175 * GDP.P+338.043 * LN(GDP.P)
- **Railways**
  - LN(PAS.RL) =1.250 -0.591 * LN(GDP.P) +1.234 * LN(PAS.T)
- **Highways**
  - PAS.RD=567.455+0.847*PAS.T-136.579*LN(GDP.P);
- **Air**
  - PAS.AIR = 22.558 +0.168 * GDP.P-8.661 * LN(PAS.T);
- **Car ownership**
  - Log((1-CAR.OW)/CAR.OW) = 3.068-0.000185*GDP.PPP.P;

Future freight ton-km projection



	Railways	Highways	other
2000	31%	14%	55%
2050	16%	30%	54%

Future passenger-km projection



	Railways	car	bus	Air&other
2000	37%	7%	48%	8%
2050	12%	35%	41%	12%

Energy intensity comparison for different transportation modes

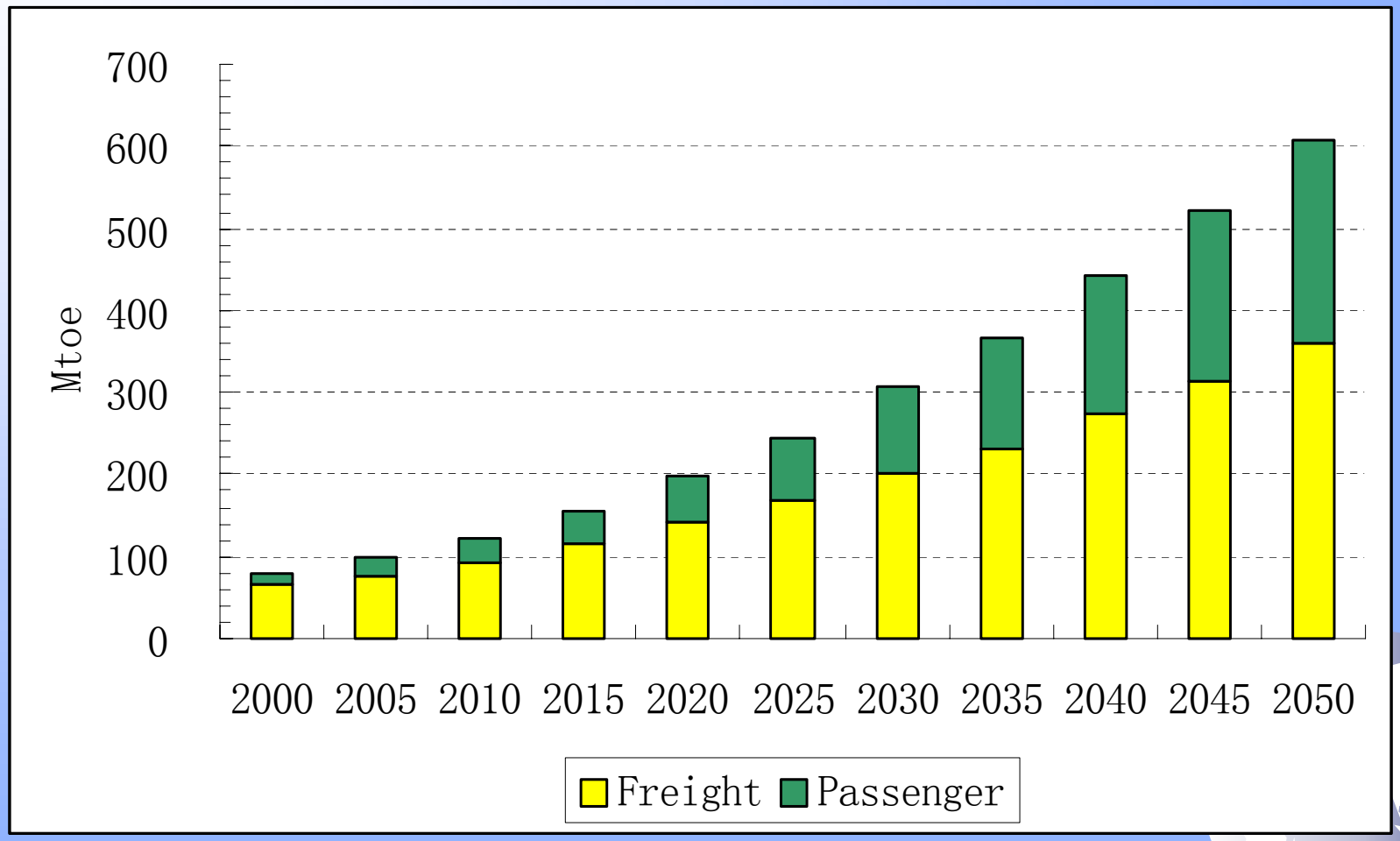
Freight

Truck (kcal/t-km)	Rail (kcal/t-km)	Water (kcal/t-km)	Air (kcal/t-km)
650	41.1	79.9	5200

Passenger

Car (kcal/km)	Bus (kcal/p-km)	Rail (kcal/p-km)	Air (kcal/p-km)
800	79	31.9	436

uture energy demand in transportation secto

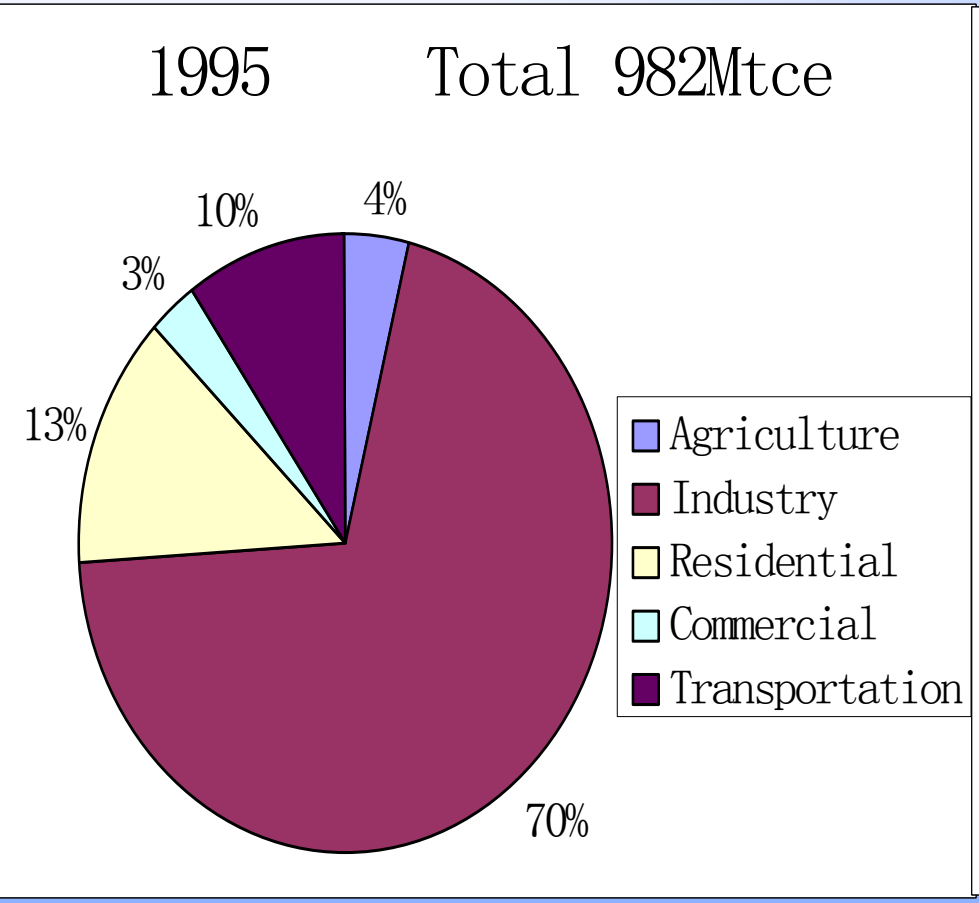


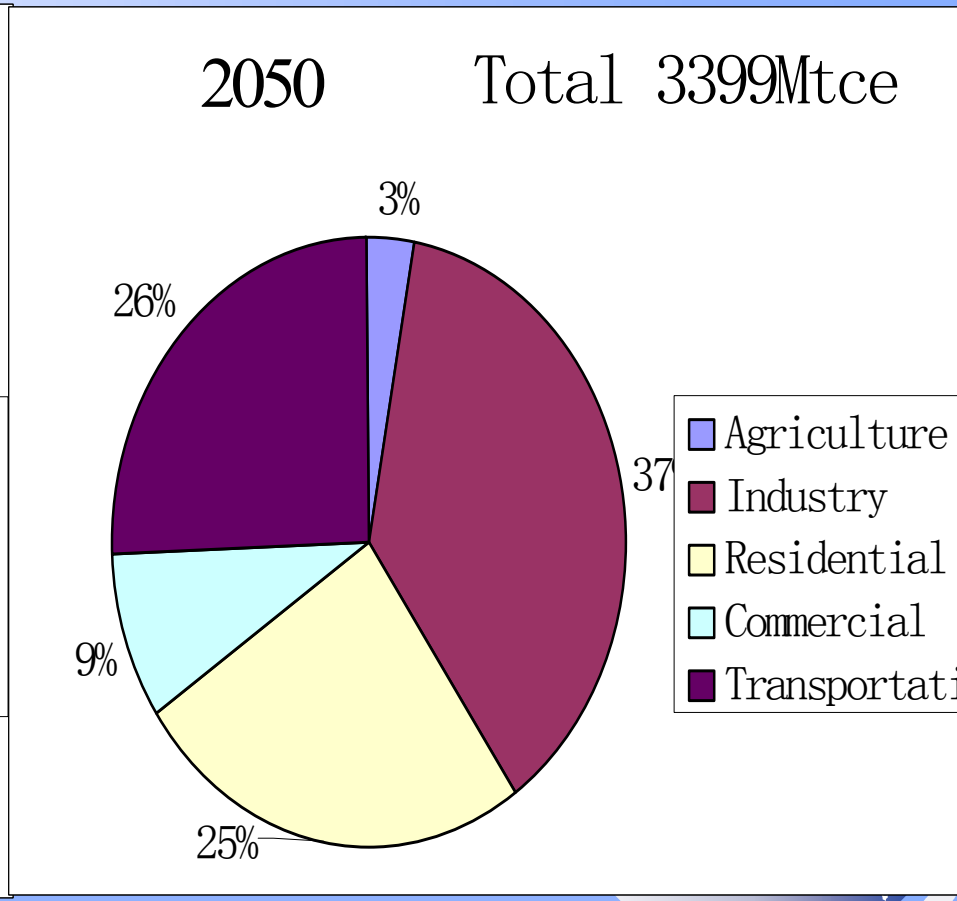
2000: 80Mtoe 2050: 618Mtoe

annual growth rate 4.1%

Modeling results for whole China

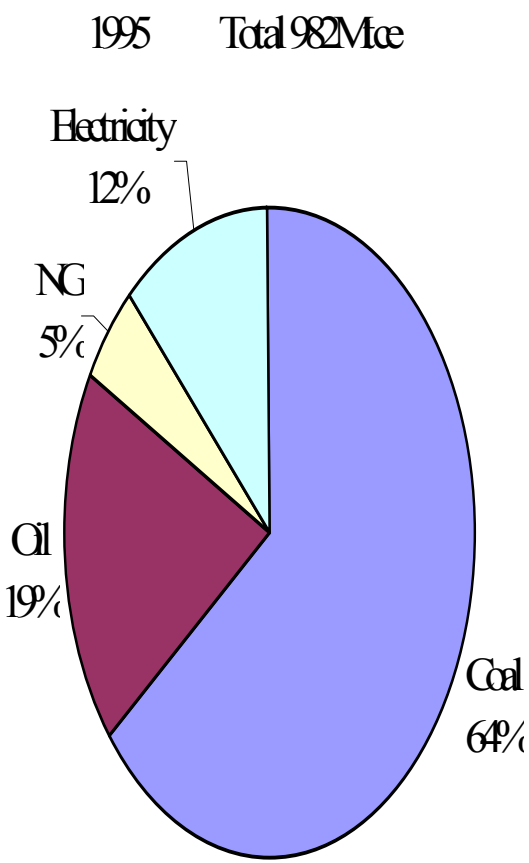
Final Energy Consumption by Sector

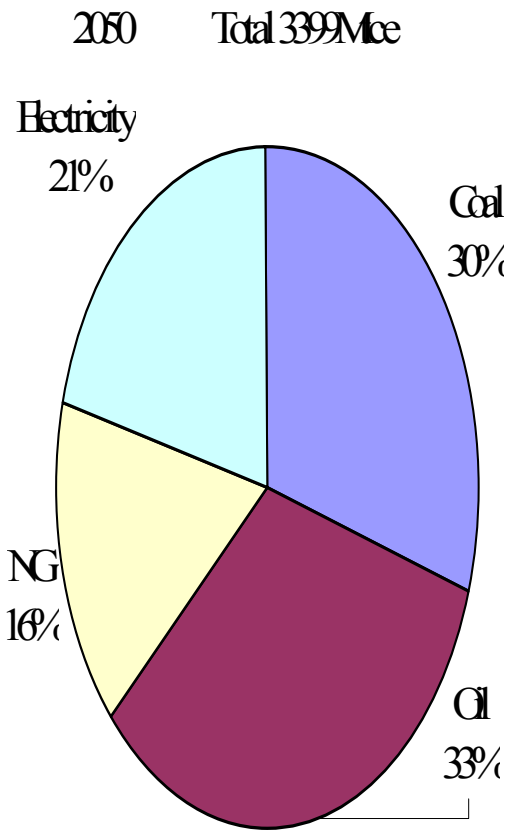




OECD 1995 : Industry 32.7%; Transportation 32.8%

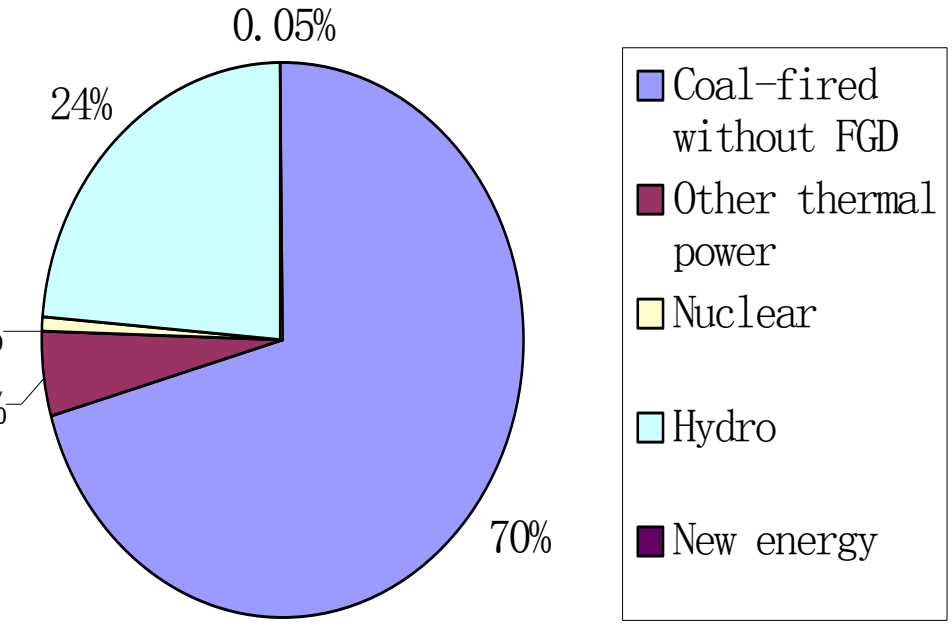
Final Energy Consumption by Fuel



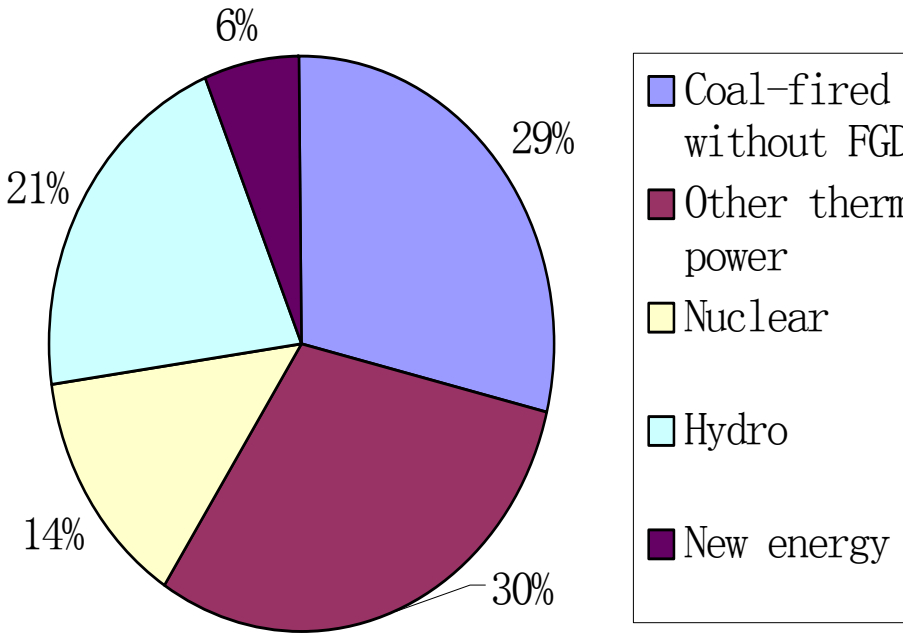


Power Capacity Mix

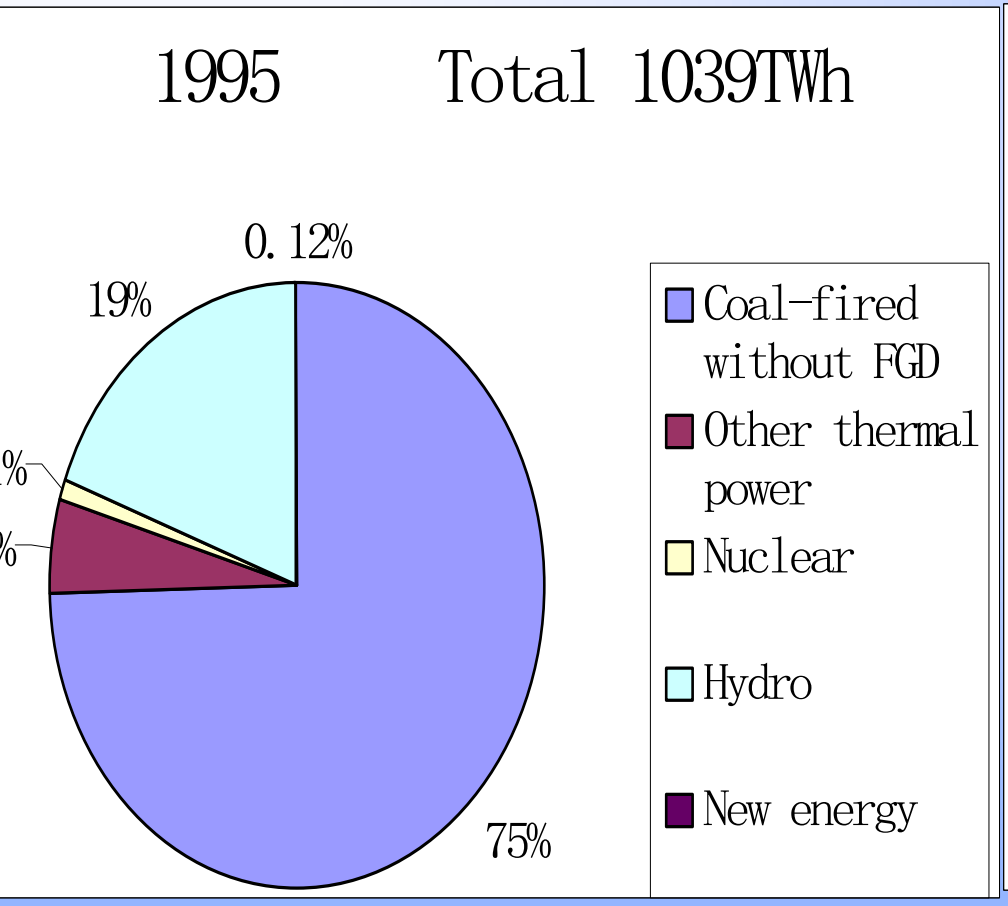
1995 Total 219GW

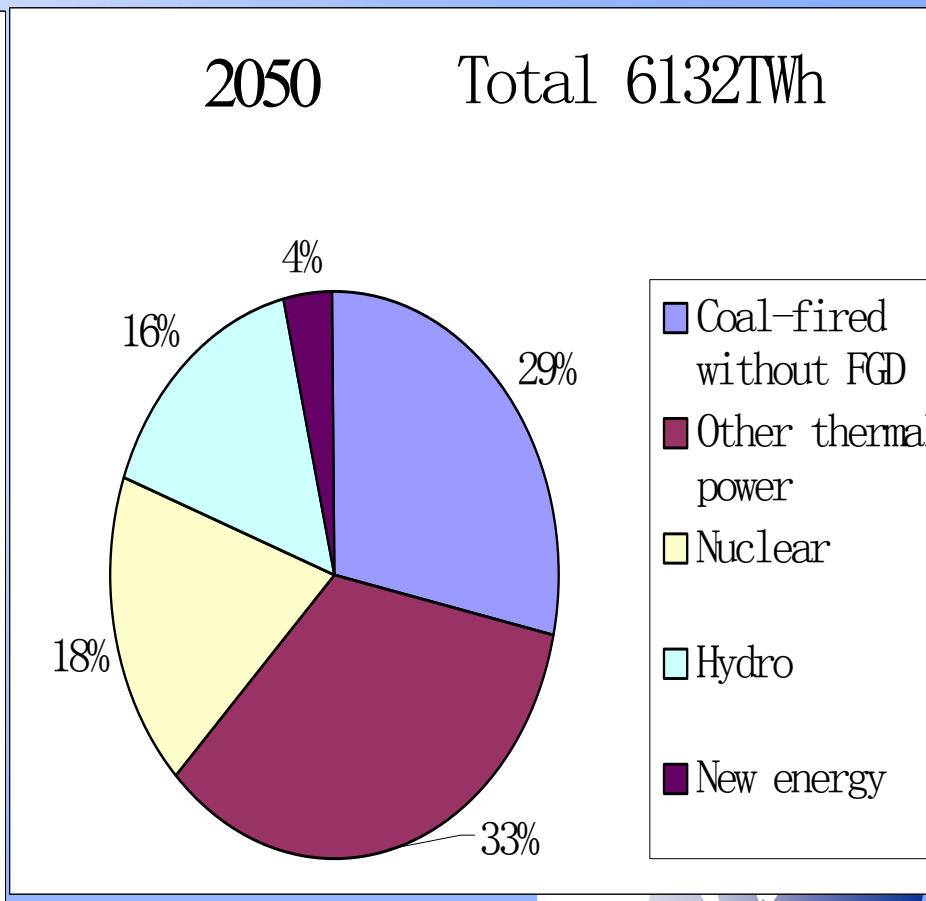


2050 Total 1169GW



Power Generation Mix

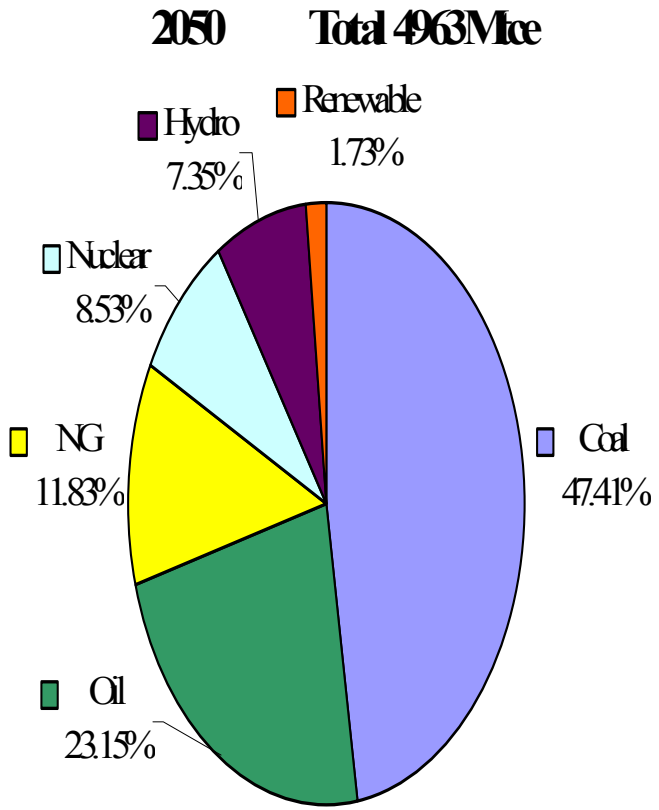




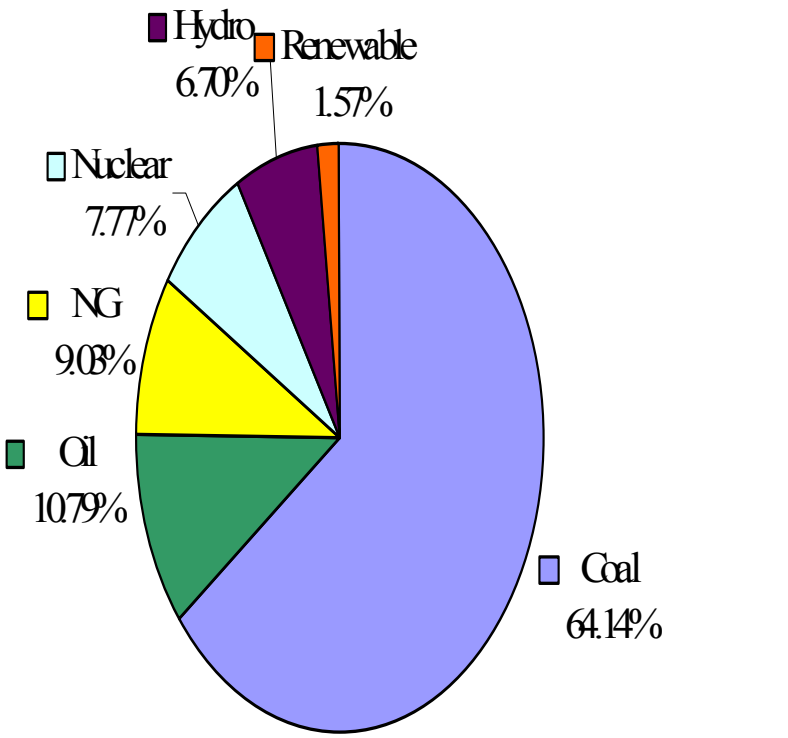
World 1995: Coal 37.5%; Oil & gas 24.6%; Hydro 18.9%; Nuclear 17.7%.

Primary Energy Consumption Mix

I



II



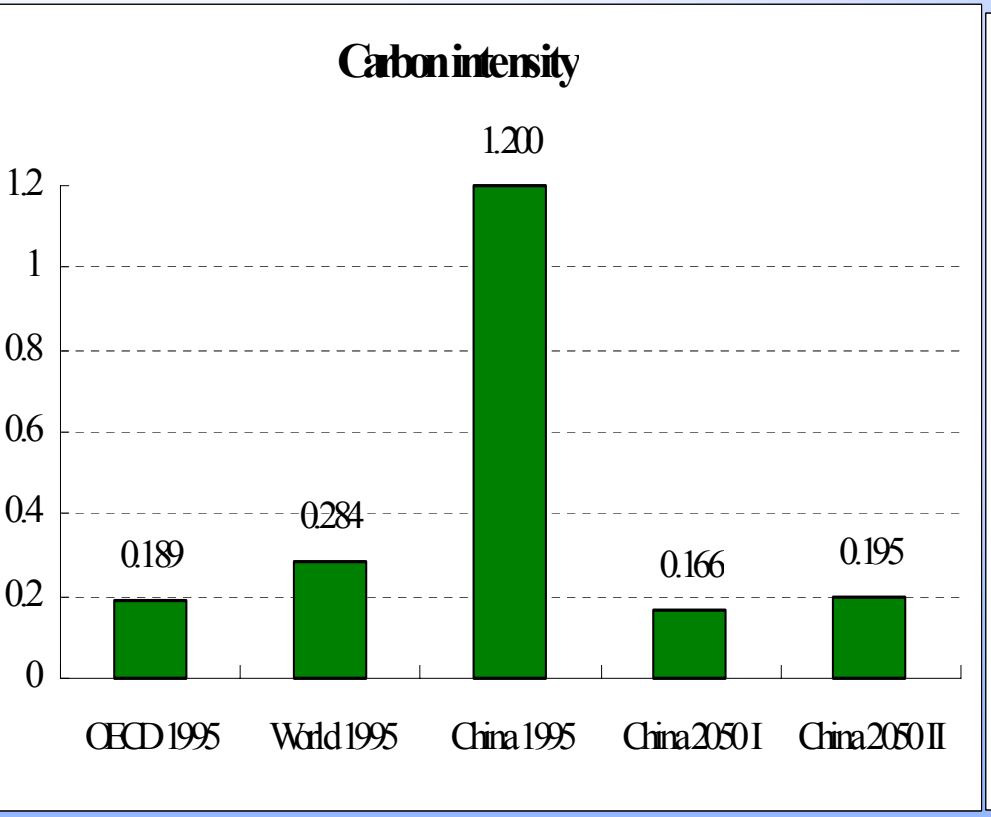
–Max. domestic oil production: 100Mtoe (143Mtce)

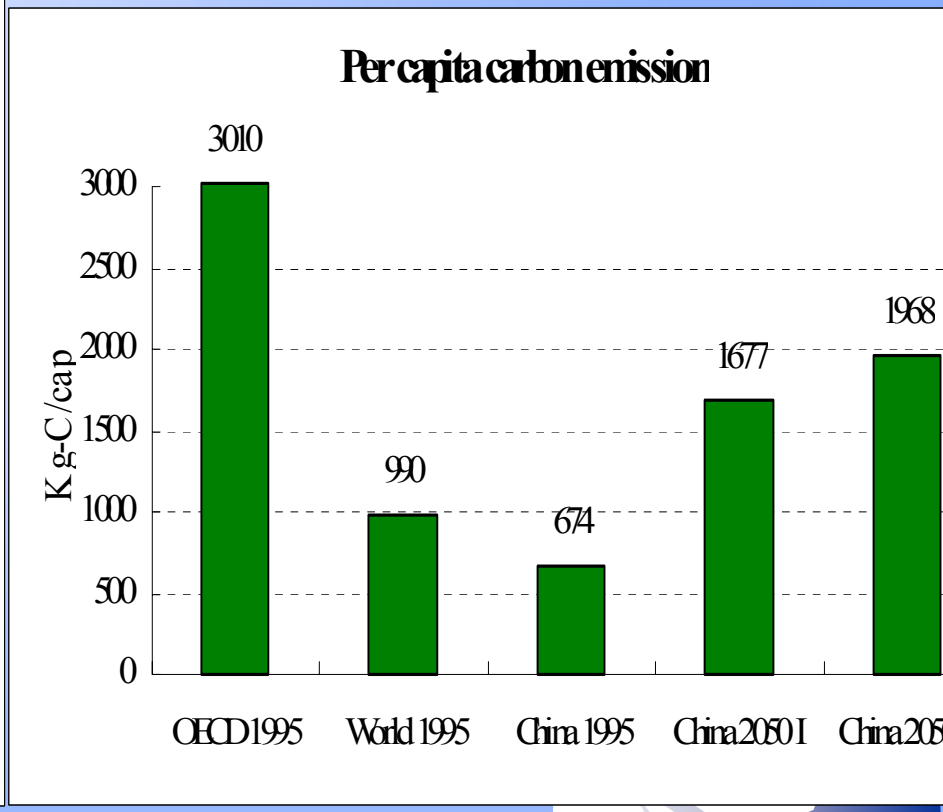
–Oil import constrain: 311Mtoe (445Mtce)

Why high coal share and more energy consumption in case II?

- **Oil**
  - **mining: 143Mtce(100Mtoe)**
  - **import: 445Mtce(311Mtoe)**
  - **total supply: 588Mtce**
  - **demand: 1025Mtce (around 75% for transportation sector)**
- **Coal liquefaction, hydrogen making is expected to be widely used to compensate the scarcity of oil supply**
- **However, efficiency only about 55%**

CO2 emission index comparison



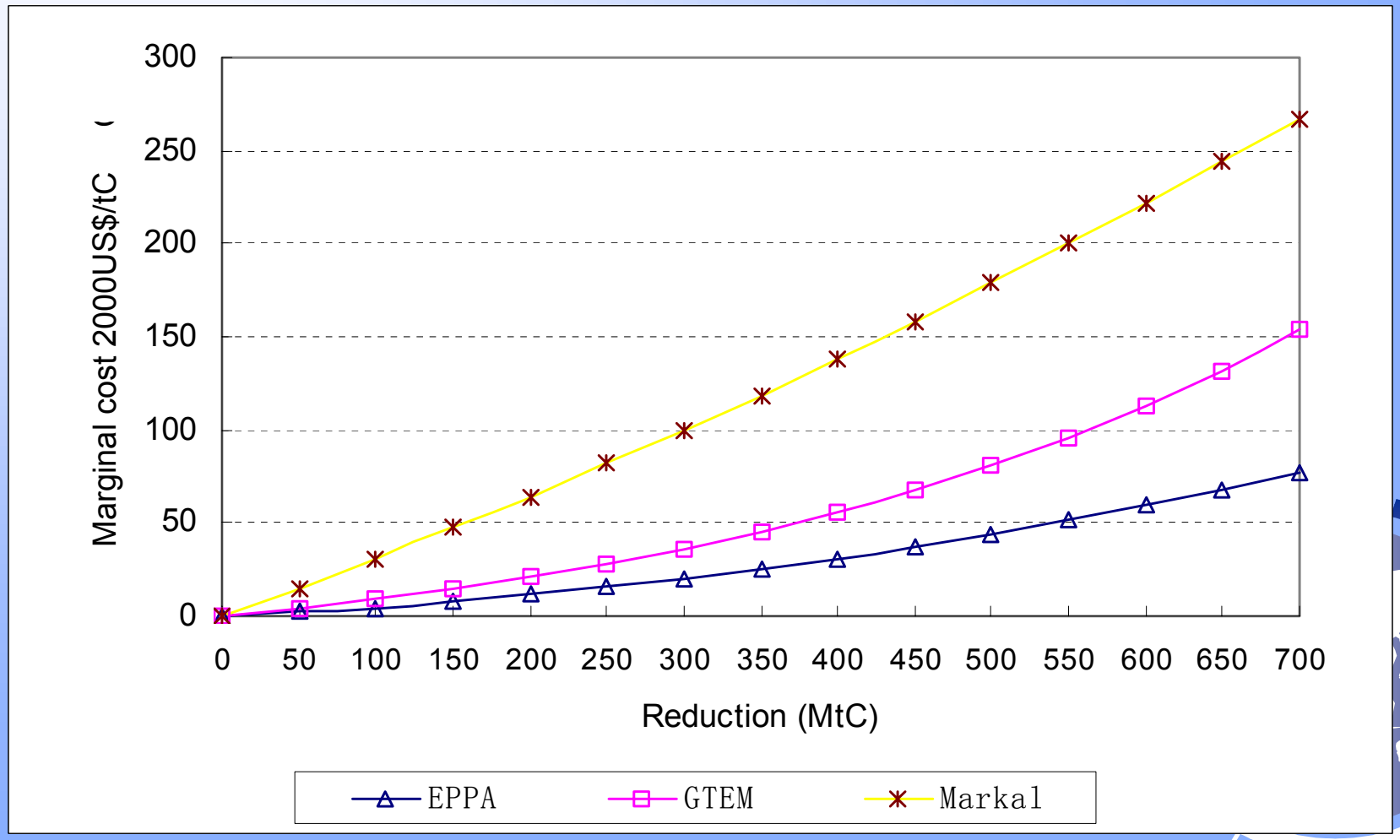


CO2 emission in 2050 for China

I: 2642Mt-C

II: 3100Mt-C (with oil import constrain)

Comparison of China's MAC from different models (2010)



Conclusions

- Although energy conservation rate is expected to maintain high in future, the primary energy consumption will hit as high as 5000Mtce or higher by 2050. More clean, new and renewable energy need to be exploited and utilized to avoid energy supply shortage, and to protect environment.
- Demand for oil is expected to grow significantly in future. Apart from strengthening exploration and exploitation of oil resource especially in west China and sea area, and establishing overseas oil bases, attention should also be paid to coal-derived synthesis transportation fuel like DME (dimethyl ether) to promote development and popularization coal-based poly-generation technologies whose efficiency are higher than coal liquefaction, hydrogen making etc.
- Overall, facing the challenges of uprising demand for energy, enlarging gap between oil demand and supply, growing concerns on local as well as global environmental protection, diversified, reliable and environmentally sound energy development strategies should be adopted for China in the new century.