The TIMES Integrated Assessment Model (TIAM): some details on model and database

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PLAN

1. The TIAM Equilibrium
2. TIAM sectors: some details
    1. Demands
    2. Technologies
    3. Trade
    4. Emissions, abatement options
3. The TIAM Climate Module
4. VEDA3 Interface

1. The TIAM EQUILIBRIUM

Storyline : lifestyle, pop dyn, technical progress, etc.

↓ C.G.E. Model (GEMINI-E3)

Drivers: GDP, sectoral outputs, etc.

↓ Demand = Driver^{elasticity}

} FOR BASE CASE ONLY

TIAM EQUILIBRIUM

End-use Demands of TIAM

MITIGATION OPTIONS

Energy, Technology, Emissions

Prices, Quantities

Climate Change (concentration, forcing, temperature)

Available Options in TIAM:

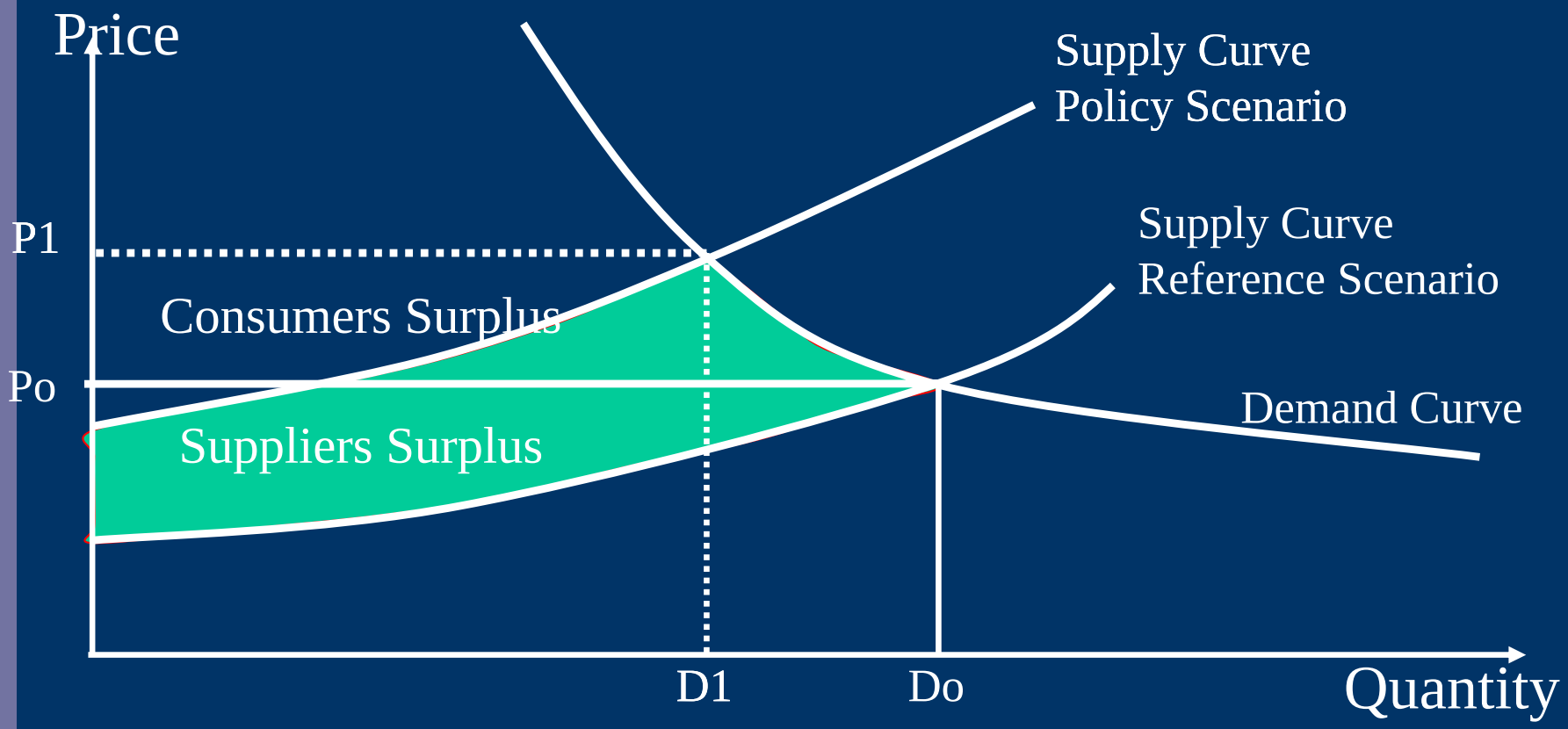
- **Energy and technology substitution**
- **Demand reduction**
- **Specific CH4 and N2O options**
- **Biological absorption of CO2**
- **Capture (electricity and hydrogen) and sequestration of CO2 (CCS)**

TIMES Integrated Assessment Model

The TIAM Equilibrium

- For each new run, TIAM simultaneously recalculates
  - Energy produced, consumed,
  - Energy prices
  - Technology adoption, abandonment
  - Emissions
  - Emission prices
  - Climate variables
  - Demands for energy services
- These quantities and prices are in equilibrium
  - Over all sectors, periods in the horizon, regions
  - The equilibrium maximizes total surplus (suppliers + consumers surpluses) via Linear Programming

(Max) Total Surplus = Consumer Surplus + Suppliers Surplus

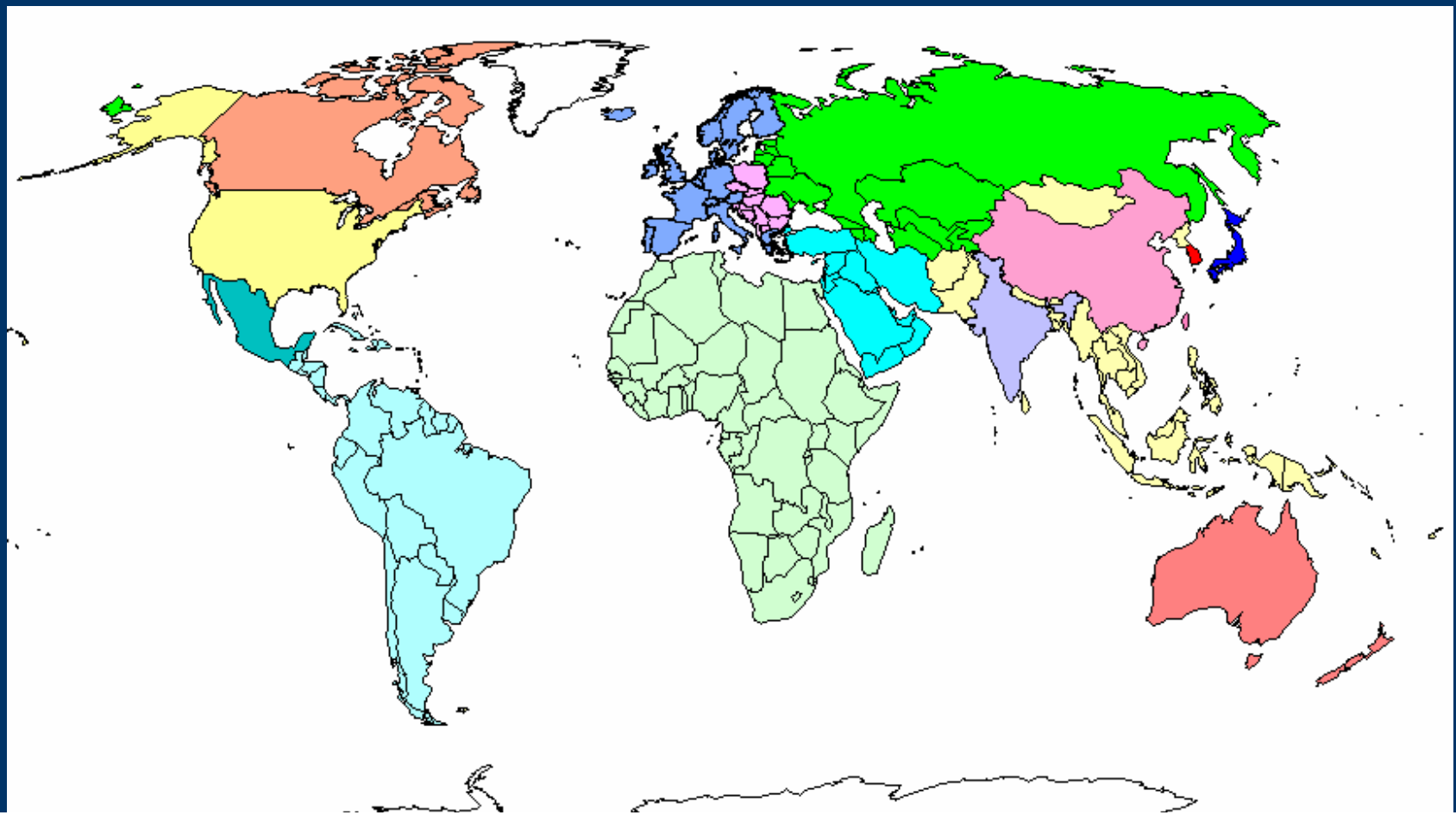


- Supply curves are implicitly constructed by TIAM
- Demand curves are implicitly constructed by TIAM
  - except for energy service demands

15 regions + OPEC/Non-OPEC

Africa*
Australia-New Zealand
Canada
Central and South America*
China
Eastern Europe
Former Soviet Union
India
Japan
Mexico
Middle-East*
Other Developing Asia*
South Korea
United States
Western Europe

* *OPEC and Non-OPEC countries are separated in primary and secondary sectors ⇒ oil production strategies and oil price control by OPEC countries*



List of countries in multi-country regions

Region	Country
AFR	Algeria, Angola, Benin, Cameroon, Congo, Congo Republic, Egypt, Ethiopia, Gabon, Ghana, Ivory Coast, Kenya, Libya, Morocco, Mozambique, Nigeria, Other Africa[a], Senegal, South Africa, Sudan, Tanzania, Tunisia, Zambia, Zimbabwe
CSA	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Other Latin America[b], Panama, Paraguay, Peru, Trinidad-Tobago, Uruguay, Venezuela
EEU	Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovakia, Slovenia, Yugoslavia
FSU	Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
MEA	Bahrain, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, Yemen
ODA	Bangladesh, Brunei, Chinese Taipei, Indonesia, North Korea, Malaysia, Myanmar, Nepal, Other Asia[c], Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam
WEU	Austria, Belgium, Denmark, Finland, France[d], Germany, Gibraltar, Greece, Greenland, Iceland, Ireland, Italy[e], Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland[f], United Kingdom

[a] Included: Botswana, Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Djibouti, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Niger, Reunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Swaziland, Togo, Uganda. Excluded due to lack of data: Comoros, Namibia, St. Helena, Western Sahara.

[b] Included: Antigua and Barbuda, Bahamas, Barbados, Belize, Bermuda, Dominica, French Guiana, Grenada, Guadeloupe, Guyana, Martinique, St. Kitts and Nevis, St. Lucia, St. Vincent and Grenadines, Suriname. Excluded due to lack of data: Aruba, British Virgin Islands, Cayman Islands, Falkland Island, Montserrat, St. Pierre and Miquelon, Turks and Caicos Islands.

[c] Included: Afghanistan, Bhutan, Fiji, French Polynesia, Kiribati, Maldives, New Caledonia, Papua-New-Guinea, Samoa, Solomon Islands, Vanuatu. Excluded due to lack of data: American Samoa, Cambodia, Christmas Island, Cook Islands, Laos, Macau, Mongolia, Nauru, Niue, Pacific Islands, Tonga, Wake Island.

[d] Includes Monaco.

[e] Includes San Marino and Vatican City

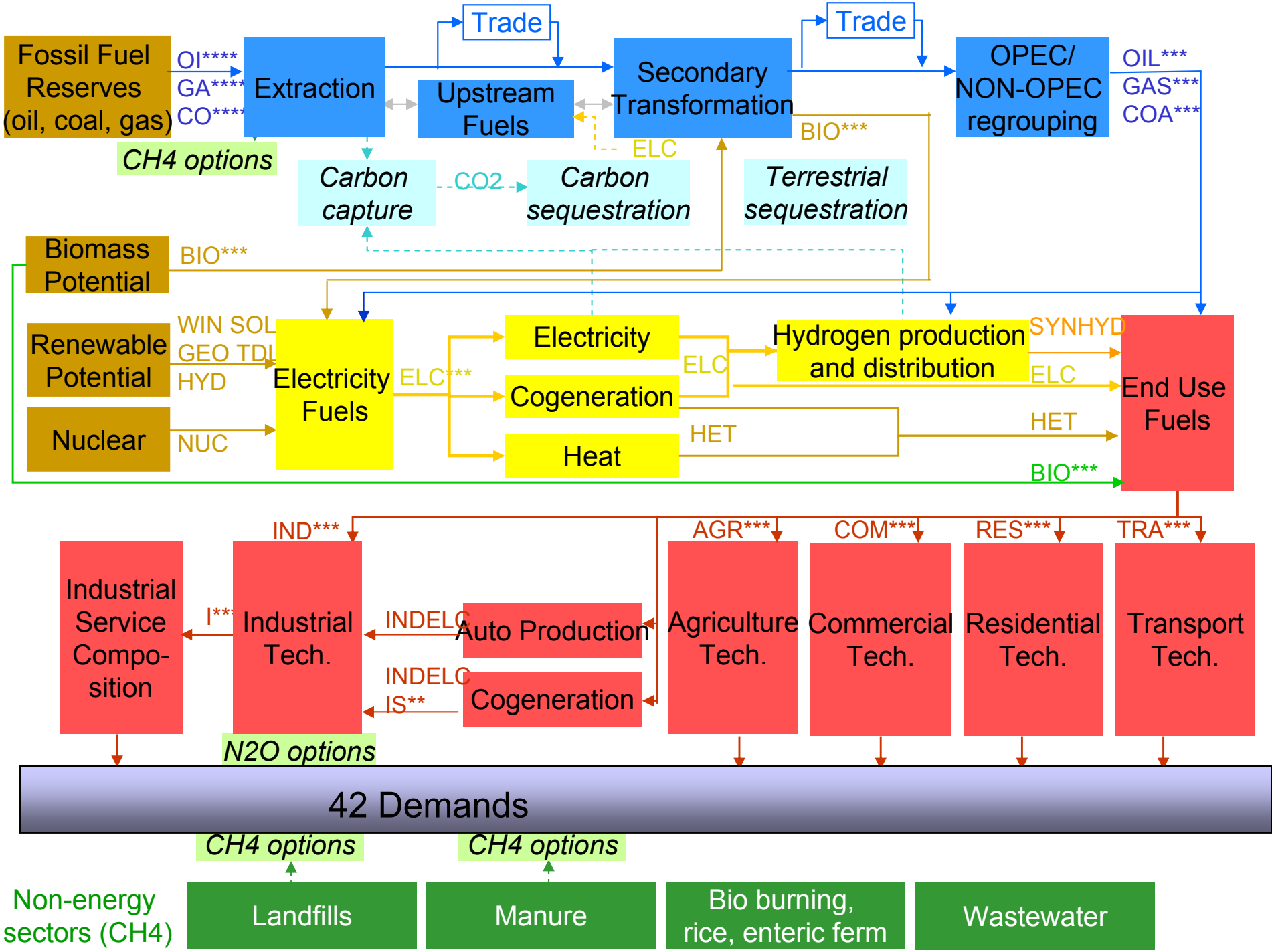
[f] Includes Liechtenstein

Reference Energy System

Climate Module

Atm.Conc
ΔForcing
ΔTemp

Used for reporting & setting targets



A. Demand projections

Storyline : population dynamics, technical progress, etc.

GEM-E3

Drivers: GDP, sectoral outputs,

GDP: moderate annual growth (2.1%)

GDP(2100) = 8*GDP(2000)

POP: from 6 to 9 billions (2000-2100)

$DEM = K*(Driver)^{elasticity}$

End-use demands of TIAM

Elasticities:
- "some" saturation in the long term
⇒ lower elasticities
- convergence between developing and industrialized countries

End-use demands (1/2)

	Code	Unit
Transportation segments (15)		
Autos	TRT	Billion vehicle-km/year
Buses	TRB	Billion vehicle-km/year
Light trucks	TRL	Billion vehicle-km/year
Commercial trucks	TRC	Billion vehicle-km/year
Medium trucks	TRM	Billion vehicle-km/year
Heavy trucks	TRH	Billion vehicle-km/year
Two wheelers	TRW	Billion vehicle-km/year
Three wheelers	TRE	Billion vehicle-km/year
International aviation	TAI	PJ/year
Domestic aviation	TAD	PJ/year
Freight rail transportation	TTF	PJ/year
Passengers rail transportation	TTP	PJ/year
Internal navigation	TWD	PJ/year
International navigation (bunkers)	TWI	PJ/year
Non-energy uses in transport	NEU	PJ/year
Residential segments (11)*		
Space heating	RH1, RH2, RH3, RH4	PJ/year
Space cooling	RC1, RC2, RC3, RC4	PJ/year
Hot water heating	RWH	PJ/year
Lighting	RL1, RL2, RL3, RL4	PJ/year
Cooking	RK1, RK2, RK3, RK4	PJ/year
Refrigerators and freezers	RRF	PJ/year
Cloth washers	RCW	PJ/year
Cloth dryers	RCD	PJ/year
Dish washers	RDW	PJ/year
Miscellaneous electric energy	REA	PJ/year
Other energy uses	ROT	PJ/year

End-use demands (2/2)

Commercial segments (8)*		
Space heating	CH1, CH2. CH3, CH4	PJ/year
Space cooling	CC1, CC2. CC3. CC4	PJ/year
Hot water heating	CHW	PJ/year
Lighting	CLA	PJ/year
Cooking	CCK	PJ/year
Refrigerators and freezers	CRF	PJ/year
Electric equipments	COE	PJ/year
Other energy uses	COT	PJ/year
Agriculture segment (1)		
Agriculture	AGR	
*Industrial segments** (6)*		
Iron and steel	IIS	Millions tonnes
Non ferrous metals	INF	Millions tonnes
Chemicals	ICH	PJ
Pulp and paper	ILP	Millions tonnes
Non metal minerals	INM	PJ
Other industries	IOI	PJ
Other segment (1)		
Other non specified energy consumption	ONO	PJ/year

Drivers used to build energy service demands in TIAM (1/2): DEM = K*DRIVER^{elasticity}

DEMAND	DRIVER	
Transportation	**All regions**	
Automobile travel	GDP/capita	
Bus travel	POP	
2 & 3 wheelers	POP	
Rail passenger travel	POP	
Domestic aviation travel	GDP	
International Aviation travel	GDP	
Trucks	GDP	
Fret rail	GDP	
Domestic Navigation	GDP	
Bunkers	GDP	
Residential	**All regions after 2050 + Non-OECD before 2050**	**OECD regions before 2050**
Space heating	HOU	HOU
Space Cooling	HOU	GDPP
Water Heating	POP	POP
Lighting	GDPP	GDPP
Cooking	POP	POP
Refrigeration and Freezing	HOU	GDPP
Washers	HOU	GDPP
Dryers	HOU	GDPP
Dish washers	HOU	GDPP
Other appliances	GDPP	GDPP
Other	HOU	GDPP

Drivers used to build energy service demands in TIAM (2/2)

DEMAND	DRIVER
Commercial	**All regions**
Space heating	SPROD-Services
Space Cooling	SPROD-Services
Water Heating	SPROD-Services
Lighting	SPROD-Services
Cooking	SPROD-Services
Refrigeration and Freezing	SPROD-Services
Other electric demands	SPROD-Services
Other	SPROD-Services
Agriculture	SPROD-Agriculture
Industry	**All regions**
Iron and steel	SPROD-I
Non ferrous metals	SPROD-I
Chemicals	SPROD-I
Pulp and paper	SPROD-O
Non metal minerals	SPROD-O
Other industries	SPROD-O

HOU: households GDPP: GDP per capita
POP: population SPROD-X: production of sector X related to GDP
GDP: gross domestic product

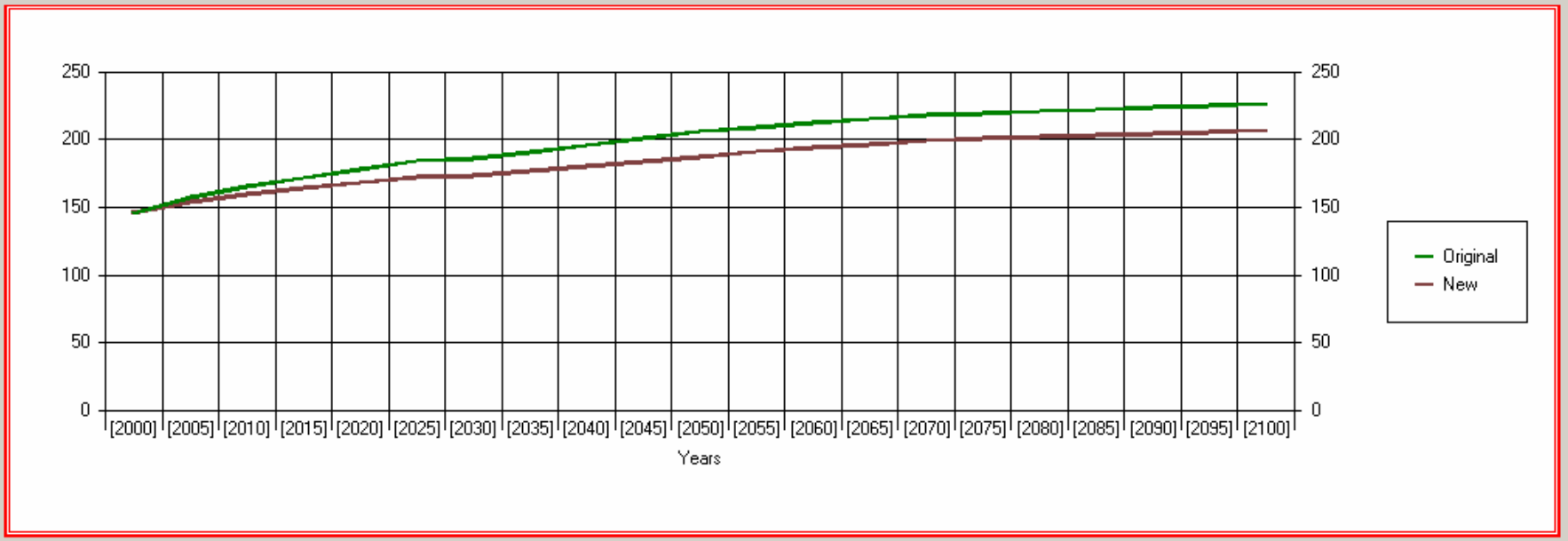
Demand handling in VEDA3

VEDA Front End-2.2.17: TIMES Model - [Edit Single Demand]

File Basic Functions Advanced Functions Tools Window Switch Mode Help

Scenario Name: BASE | Select Region: WEU | Select Demand: TRH | Road Heavy Trucks Demand | Years: | SAVE | CANCEL | CLOSE

	A	E	F	G	H	I	J	K	L	M	N	O	P
2	Select Driver	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
3	GDP	1.26	1.32	1.39	1.41	1.46	1.52	1.57	1.63	1.69	1.76	1.81	1.88
4	<New Driver>												
5													
6	Select Calibration Series												
7	A_Constant	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	*<New Series>*												
9													
10	Select Sensitivity Series												
11	WEUTRH	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.40	0.40	0.40	0.40
12	*<New Series>*	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.40
13													



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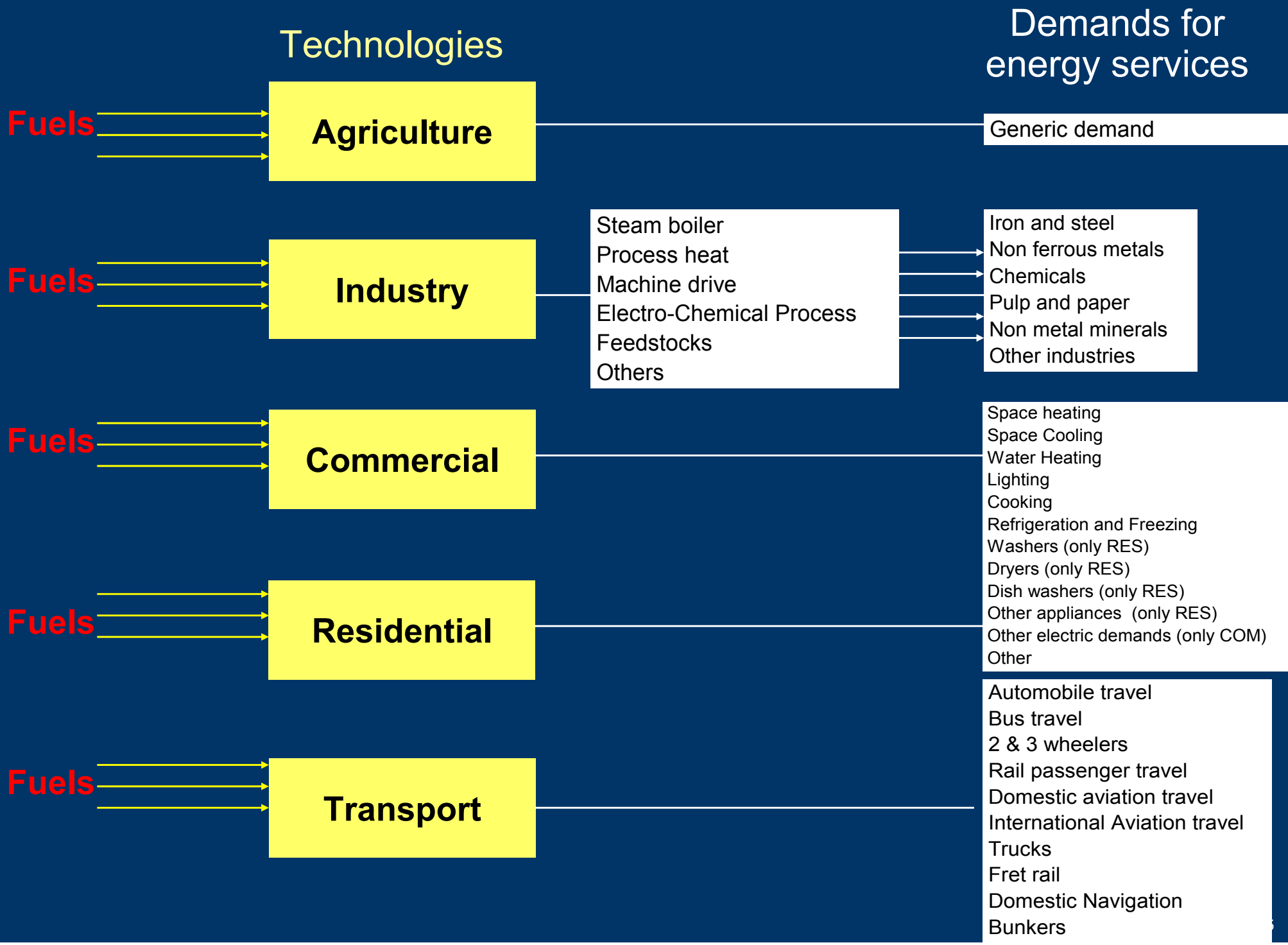
TIMES Integrated Assessment Model

B. End-Use sectors



C. Calibration to initial year

Calibration consists in matching detailed energy balances in initial period (Base year =2000)

Data sources:

Energy Statistics and Balances of OECD and Non-OECD countries given by the International Energy Agency

Adjusted by regional or national statistics if necessary and available

International and region specific statistics (installed capacities and resource potentials) from many sources (IEA-ETP, USDOE, USEPA, USGS, EGRID, NRCAN, WEC, etc.)

D. Primary and secondary energy sectors

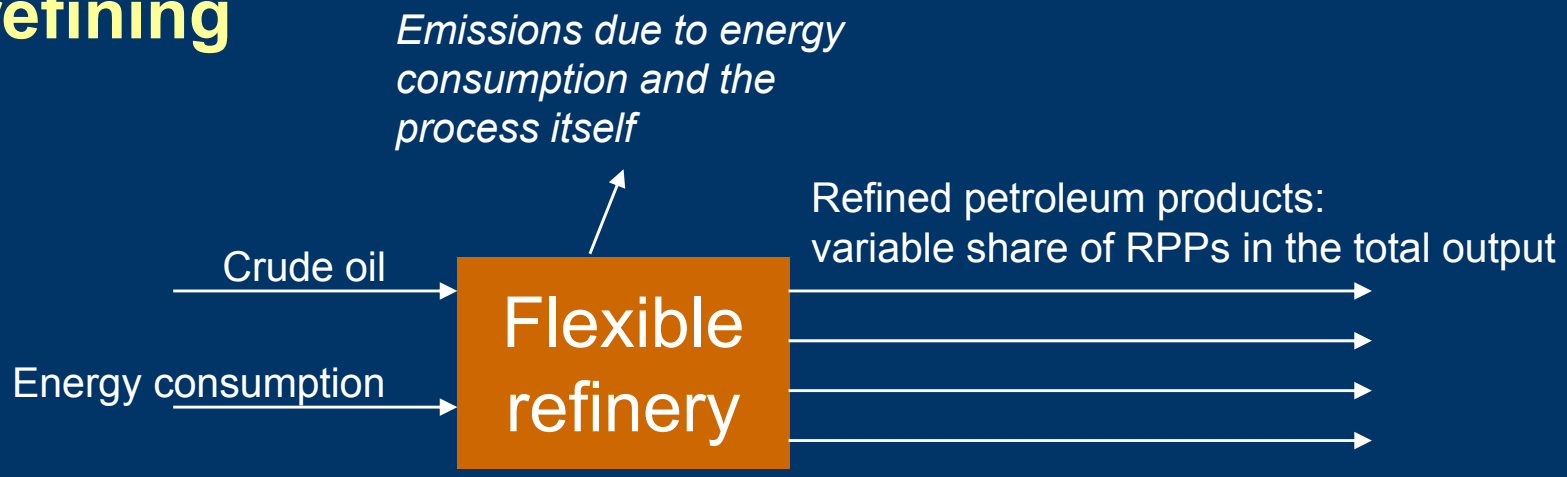
Fossil resources and extraction

Different types of reserves (characteristics of the resource, cumulative potential, cost)

Eg. Oil: 21 (conventional, oil sands, located, enhanced recovery, new discovery…)
Gas: 9 (conventional, unconventional, not connected)
Coal: 4 (brown coal, hard coal, located, new discovery)

►*Reviewed and revised by IER (Stuttgart) in 2006*

Oil refining



D. Primary and secondary energy (cont'd)

Renewable and nuclear

Geothermal: Shallow, deep and very deep

Hydro: Dam and run-of-river
WEC technical potential

Wind: Four plant-and-location combinations (different costs and AF)
Equivalent to 10% of the theoretical potential provided by IPCC-TAR ~ WEC assuming 4% of the land area

Solar

Nuclear: Basecase = min of 64 EJ/yr, max of 95 EJ/yr in 2100

Biomass: Includes industrial wastes, municipal wastes, solid biomass, biogas from landfills, liquids from biomass (IEA categories)
World potential = 238 EJ in 2100
Practical and technical constraints (distance of a biomass production site from demand centres, land-use conflicts)

Main sources of data

IEA-ETP, World Energy Council, IPCC-TAR, US Geological Survey, …

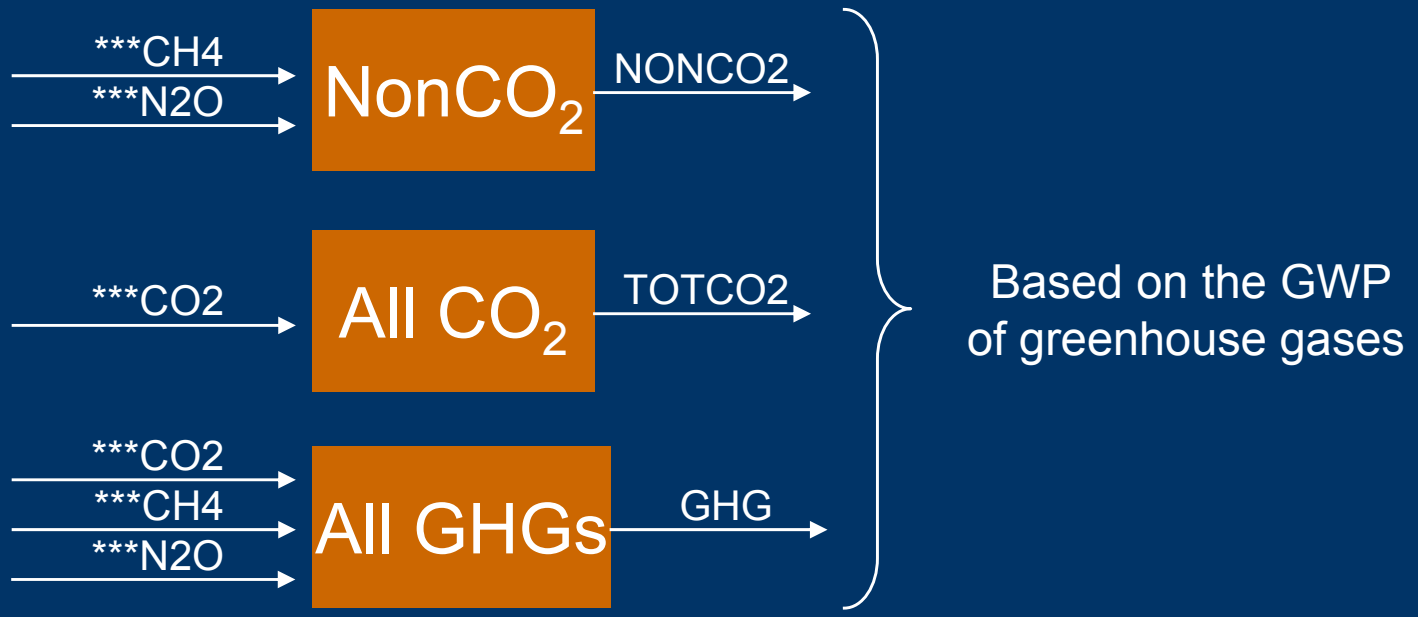
E. Energy and emission trade

- Endogenous trade of coal, crude oil, gas, liquefied gas *(revised by IER)*

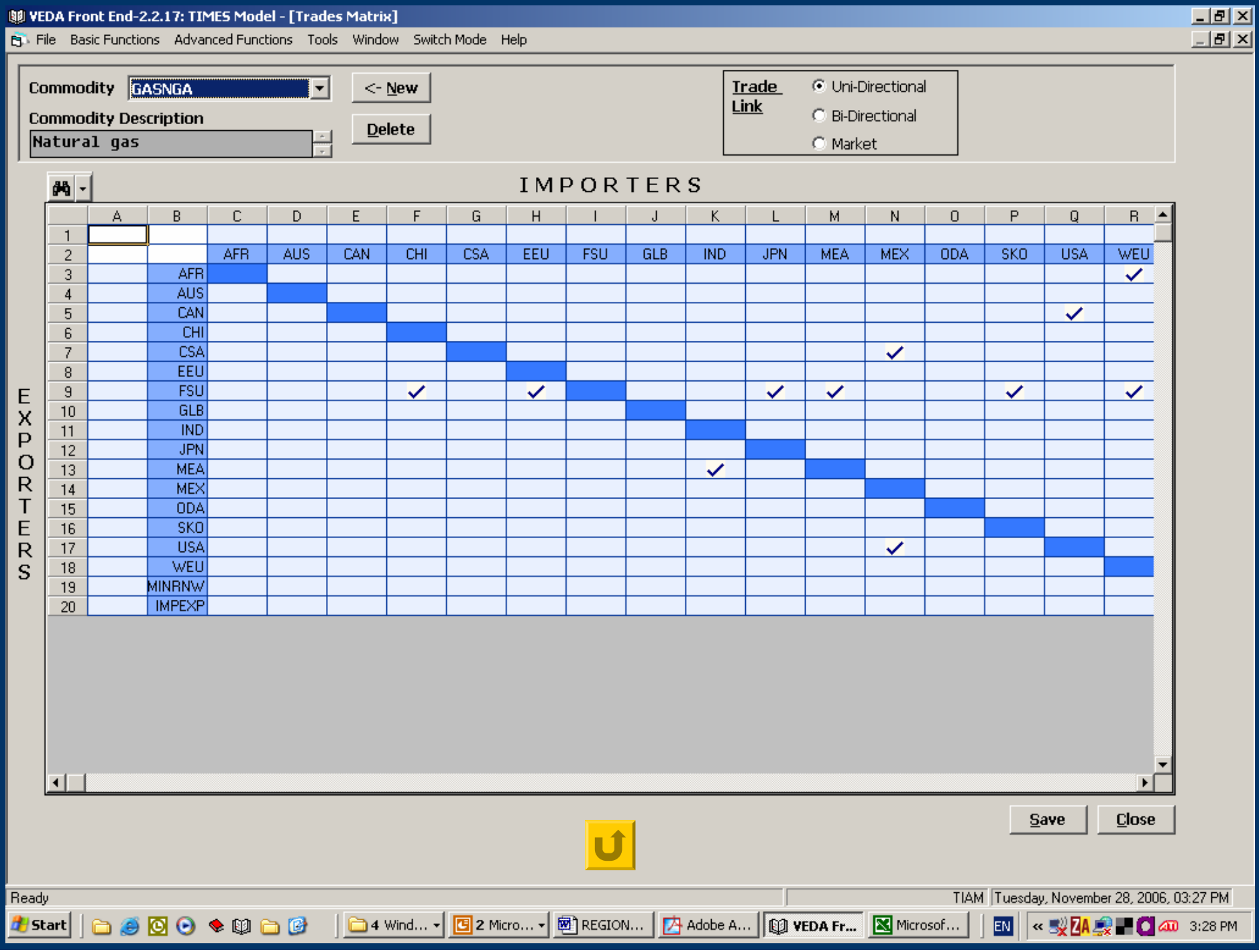
⇒ price and amount of traded energy are endogenous

⇒ the impact of environmental policies on trade is simulated

- Endogenous trade of CO_2 (or GHG) permits
- The user can choose which gases/energy commodity and which regions are included in trade (eg. only CO_2, all GHGs, only some countries)



E. Defining endogenous trade in VEDA3



E. Oil pricing, Gas Pricing

- **Oil market is not competitive. Cartel (OPEC) fixes production, other producers top-up to satisfy demand.**
- **Modeled as a leader-follower game as follows:**
  1. Fix upper bound on OPEC oil production
  2. Run model: find out market response by other producers and by consumers, as well as world price
  3. Modify upper bound
  4. Repeat steps 1,2,3, until OPEC profits are maximised

– **Gas markets are regional. TIAM assumes competitive markets: price = marginal value in each region**

F. Electricity sector (cogen and autoprod not shown)

Regional templates — 16 existing power plants

SubRes NewTech — 51 new power plants

SubRes Sequestration — 10 power plants with CO_2 capture

The price of electricity generated by power plants with CO_2 capture ~ 50% higher than the electricity price generated by power plants without capture.

Remarks

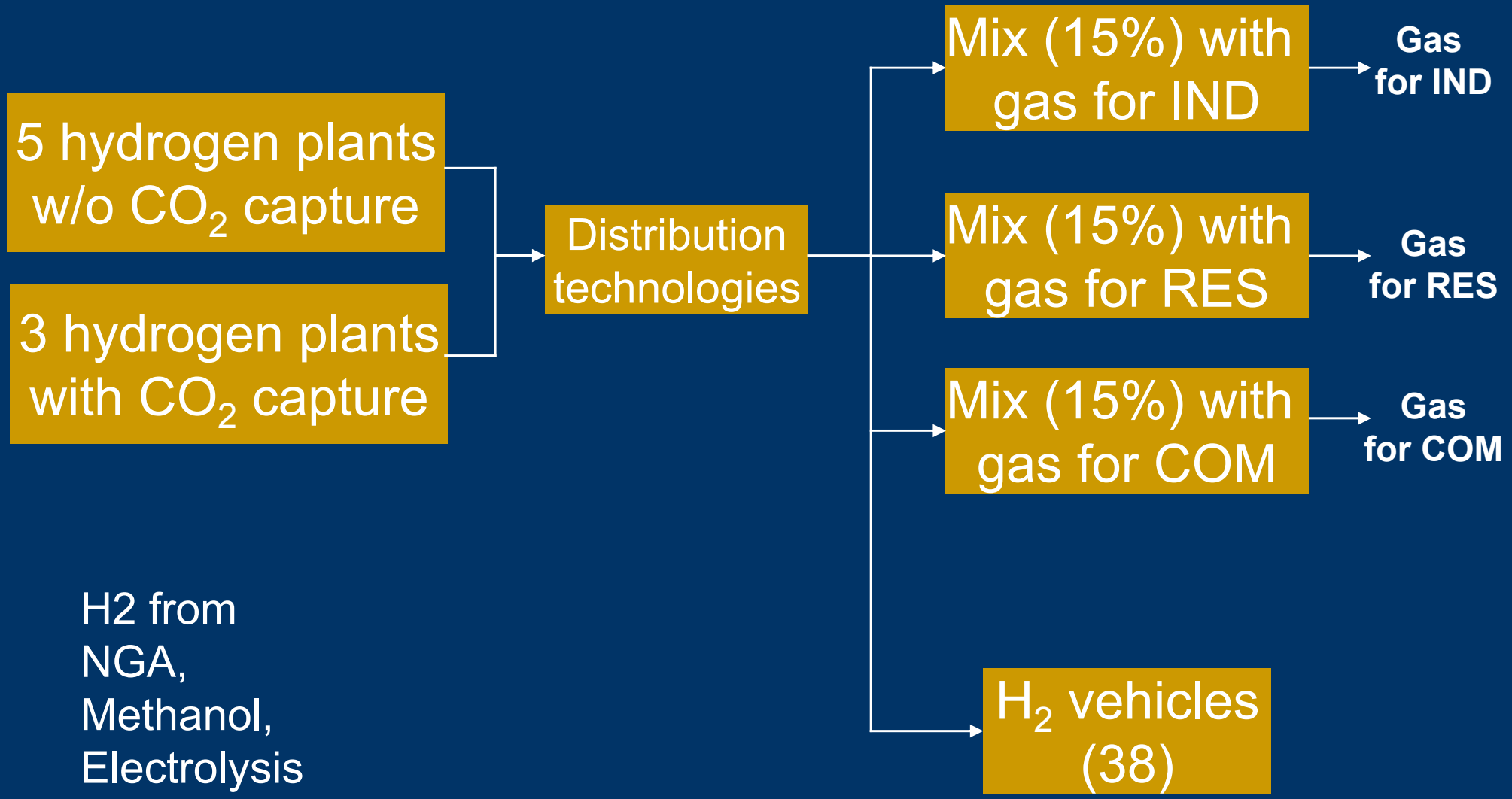
Limited share of coal plants in the total electricity produced by fossil fuel power plants (local air quality requirements)

Examples of results

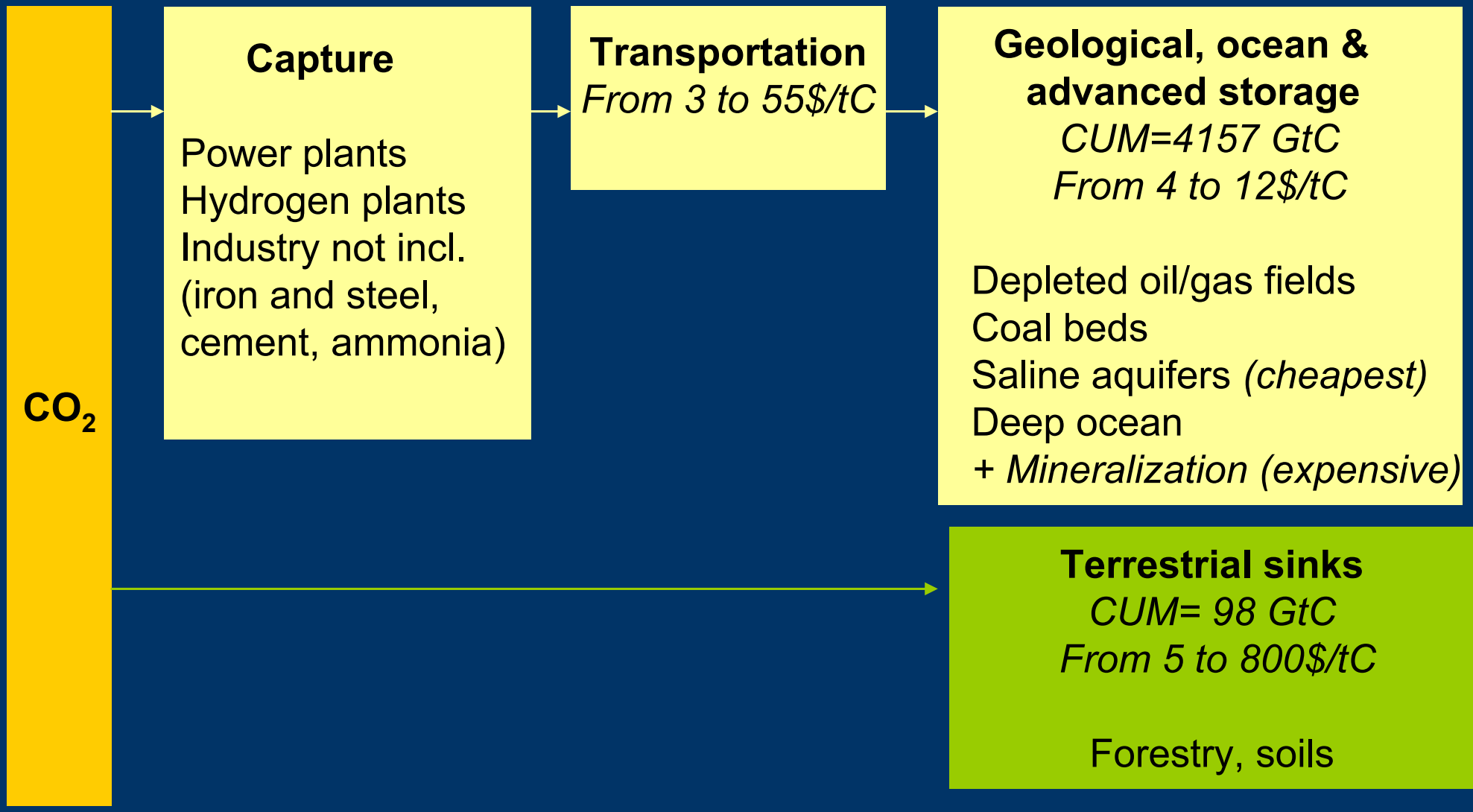
CCGT bridges the transition to more advanced fossil and zero-carbon plants

Primary consumption of coal may increase in the long term when associated with CCS and with the removal of the coal power plants limit (assuming new coal power plants are “clean” plants)

G. Hydrogen sector



H. CO_2 capture and sequestration



Remark

Sources of data: IEA-ETP, EMF-22 (EPA), literature, IPCC,

I. CH_4 emissions and abatement options (energy and non-energy – EMF21&22)

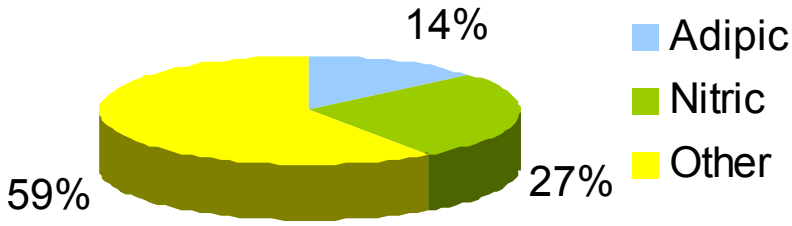
	% modeled CH4 emissions in 2000 TIAM	Abatement technologies EMF	Abatement technologies TIAM
Non-energy emissions			
Manure	4%	5	4
Landfill	13%	11	11
Wastewater	10%	0	0
Biomass burning, Enteric Fermentation, Rice	46%	0	0
Energy emissions			
Primary oil	2%	4	4
Coal mining	7%	8	8
Gas production, transmission and distribution	13%	35	14
Biofuel combustion	4%	-	Many
Fuel combustion (stationary and mobile)	1%	-	Many
Total	*100 %*	*63*	*41*

CH4 abatement options

Some EMF options were not modeled due to very high cost or very small potential (eg. some I&M options related to gas pipelines)

Combustion (energy sectors): many options available in TIAM (energy substitution or penetration of more efficient technologies)

I. CH_4 and N_2O (energy and non-energy – EMF22)



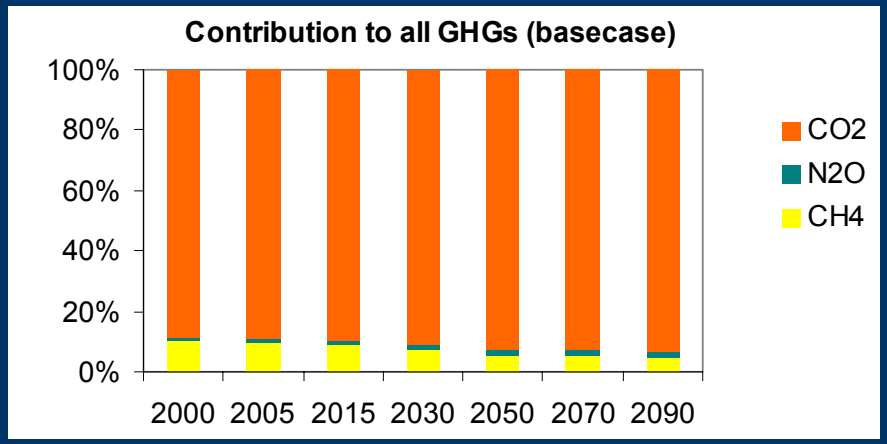
Examples of options for N2O

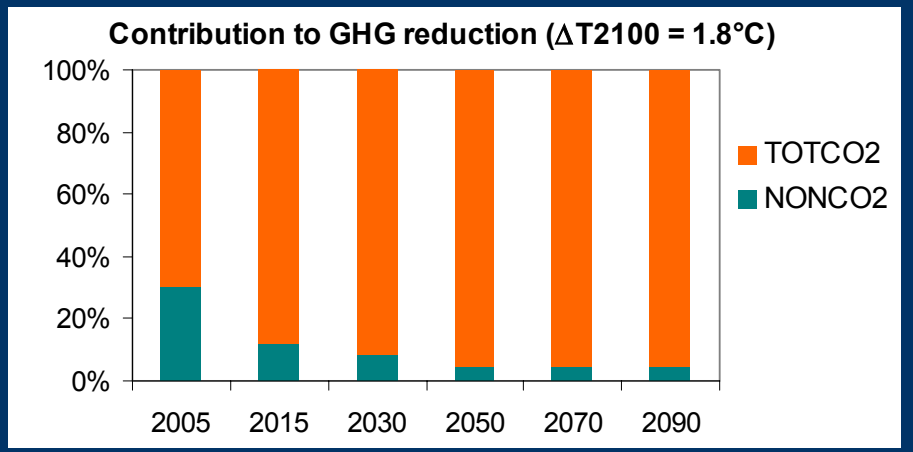
Different types of catalytic reduction, thermal destruction

Remarks

Some no-regret CH_4 mitigation options penetrate in base case (mostly production of "cheap" gas or electricity) - Also observed by US-EPA using MARKAL for the US

CH_4 and N_2O options help for GHG reduction in the short term





I. CH4 abatement options (1/2)

Manure	
ACH4MAN01	Farm Scale Digesters-A (cool climate)
ACH4MAN02	Farm Scale Digesters-A (warm climate)
ACH4MAN03	Farm Scale Digesters-B (cool climate)
ACH4MAN04	Farm Scale Digesters-B (warm climate)
Not modeled	*Centralized Digesters (cool climate)*
Landfill	
RCH4WLF01	Anaerobic digestion 1 (AD1)
RCH4WLF02	Anaerobic digestion 2 (AD2)
RCH4WLF03	Composting (C1)
RCH4WLF04	Mechanical Biological Treatment
RCH4WLF05	Heat Production
RCH4WLF06	Increased Oxidation
RCH4WLF07	Direct Gas Use (profitable at base price)
RCH4WLF08	Electricity Generation
RCH4WLF09	Direct Gas Use (profitable above base price)
RCH4WLF10	Flaring
RCH4WLF11	Composting (C2)
Primary oil	
UNCH4OIL01	Flaring instead of Venting (Offshore)
UNCH4OIL02	Flaring instead of Venting (Onshore)
UNCH4OIL03	Associated Gas (vented) Mix with Other Options
UNCH4OIL04	Associated Gas (flared) Mix with Other Options
	+ Same options for OPEC
Coal mining	
UNCH4COA01	Degasification and Pipeline Injection
UNCH4COA02	Enhanced Degasification, Gas Enrichment, and Pipeline Injection
UNCH4COA03	Catalytic Oxidation (US)
UNCH4COA04	Flaring
UNCH4COA05	Degasification and Power Production – A
UNCH4COA06	Degasification and Power Production – B
UNCH4COA07	Degasification and Power Production – C
UNCH4COA08	Catalytic Oxidation (EU)
	+ Same options for OPEC

I. CH4 abatement options (2/2)

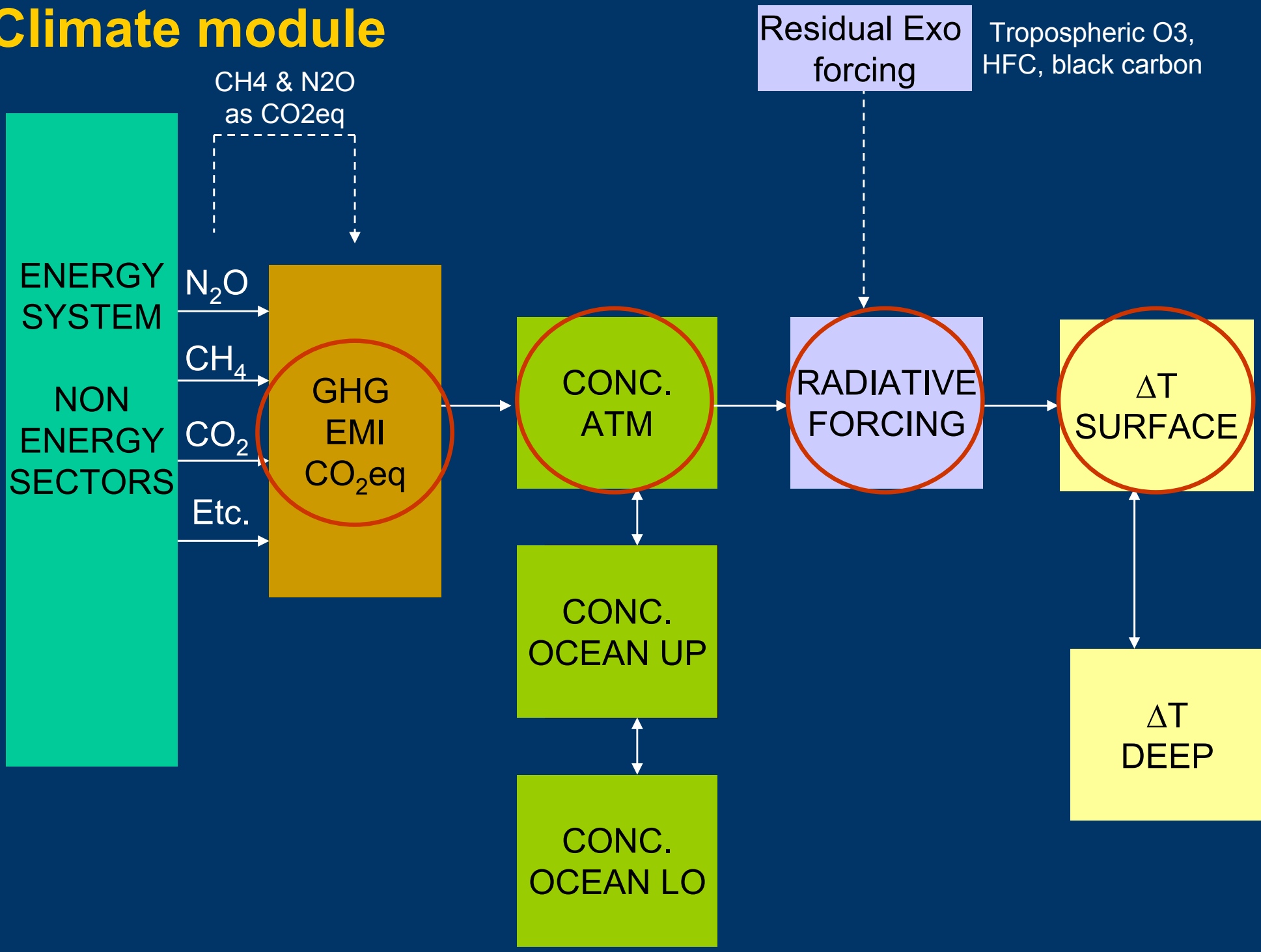
Gas production, transmission and distribution	
UNCH4GAS01	P&T - Use gas turbines instead of reciprocating engines
UNCH4GAS02	Prod-D I&M (Pipeline Leaks)
UNCH4GAS03	Installation of Flash Tank Separators (Production)
UNCH4GAS04	Replace high-bleed pneumatic devices with compressed air systems (Production)
UNCH4GAS05	Replace high-bleed pneumatic devices with low-bleed pneumatic devices (Production)
UNCH4GAS06	Dry Seals on Centrifugal Compressors (P&T)
UNCH4GAS07	Catalytic Converter (P&T)
UNCH4GAS08	Portable Evacuation Compressor for Pipeline Venting (P&T)
UNCH4GAS09	Replace High-bleed pneumatic devices with compressed air systems (P&T)
UNCH4GAS10	Replace high-bleed pneumatic devices with low-bleed pneumatic devices (P&T)
UNCH4GAS11	D-D I&M (Distribution)
UNCH4GAS12	D-D I&M (Enhanced: Distribution)
UNCH4GAS13	Electronic Monitoring at Large Surface Facilities (D)
UNCH4GAS14	Replacement of Cast Iron/Unprotected Steel Pipeline (D)
	+ Same options for OPEC
Not modeled	*P&T - Compressors-Altering Start-Up Procedure during Maintenance*
	Prod-D I&M (Chemical Inspection Pumps)
	Prod-D I&M (Enhanced)
	Prod-D I&M (Offshore)
	Prod-D I&M (Onshore)
	Installation of Electric Starters on Compressors (Production)
	Installing Plunger Lift Systems In Gas Wells
	Portable Evacuation Compressor for Pipeline Venting (Production)
	Reducing the Glycol Circulation Rates in Dehydrators (Production)
	Surge Vessels for Station/Well Venting (Production)
	Fuel Gas Retrofit for Blowdown Valve
	Reducing the Glycol Circulation Rates in Dehydrators (P&T)
	P&T-D I&M (Compressor Stations)
	P&T-D I&M (Compressor Stations: Enhanced)
	P&T-D I&M (Enhanced: Storage Wells)
	P&T-D I&M (Pipeline: Transmission)
	P&T-D I&M (Wells: Storage)
	Installation of Flash Tank Separators (P&T)
	Portable Evacuation Compressor for Pipeline Venting (P&T)
	Static-Pacs on reciprocating compressors (P&T)
	Surge Vessels for Station/Well Venting (P&T)

I. N2O abatement options

Adipic Acid	
ICH4ADI01	Thermal Destruction
Nitric Acid	
ICH4NIT01	Grand Paroisse - High Temperature Catalytic Reduction Method
ICH4NIT02	BASF - High Temperature Catalytic Reduction Method
ICH4NIT03	Norsk Hydro - High Temperature Catalytic Reduction Method
ICH4NIT04	HITK – High Temperature Catalytic Reduction Method
ICH4NIT05	Krupp Uhde - Low Temperature Catalytic Reduction Method
ICH4NIT06	ECN - Low temperature selective catalytic reduction with propane addition
ICH4NIT07	Non-Selective Catalytic Reduction (NSCR)

II. CLIMATE MODULE

Climate module



Climate equations
(as adapted from Nordhaus and Boyer, 1999)

Concentrations of GHG (in CO2-equivalent) (3 layer model)

1. $CO2_{atm}(t) = Emi(t) + CO2_{atm}(t-1)*(1-f_{atm,up}) + CO2_{up}(t-1)*f_{up,atm}$
2. $CO2_{up}(t) = CO2_{up}(t-1)*(1-f_{up,atm} -f_{up,lo}) + CO2_{lo}(t-1)* f_{lo,up} + CO2_{atm}(t-)*f_{atm,up}$
3. $CO2_{lo}(t) = CO2_{lo}(t-1)*(1-f_{lo,up}) + CO2_{up}(t-1)* f_{up,lo}$

Atmospheric forcing

4. $\Delta F(t) = \gamma/ln2 * ln [CO2_{atm}(t)/CO2_{atm} (pre\text{-}ind)] + O(t)$

Temperatures (2 layers)

Lag parameter

Climate sensitivity

5. $\Delta T_{up}(t) = \Delta T_{up}(t-1) + \mathbf{\sigma_1}*\{\Delta F(t) - 3.7/\mathbf{C_s} *\Delta T_{up}(t-1) - \sigma_2 [\Delta T_{up}(t-1) - \Delta T_{lo} (t-1)] \}$
6. $\Delta T_{lo}(t) = \Delta T_{up}(t-1)* \sigma_3 + \Delta T_{lo} (t-1)* g_{22}$

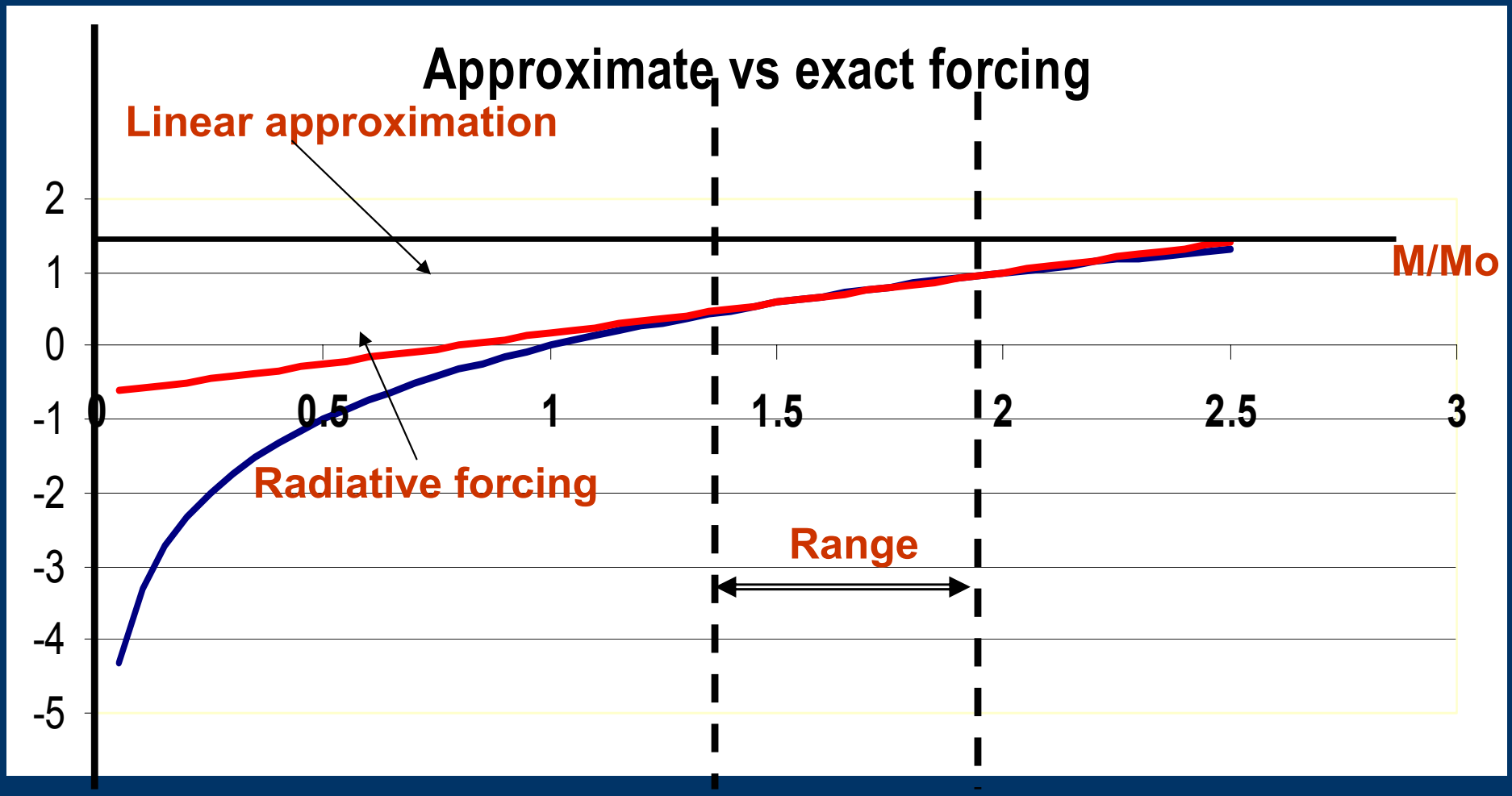
New version of the Climate Module

- The non-linear forcing equation is replaced by a (very good) linear approximation within the interval of interest For instance : (375 ppm-550 ppm)

- The approximation is halfway between the tangent and the chord of the exact logarithmic curve

- Within the selected range, the error made on Forcing never exceeds 2% (well within the inherent uncertainty on forcing values)

Linearized forcing equation



Relative error less than 2% in range (375 ppm; 550 ppm)