

# Structure of the TIMES Integrated Assessment Model (TIAM)

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## Objective

Present the structure of the TIMES Integrated Assessment Model (TIAM)

Qualitative description

Fossil resources: Uwe Remme  
Climate module: Antti Lehtila  
Stochastic analysis: Richard Loulou

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TIMES Integrated Assessment Model

## Regions, RES, framework of analysis using TIAM

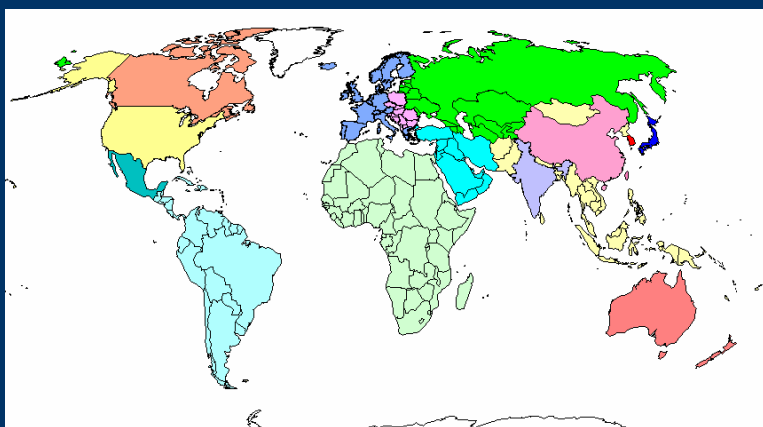
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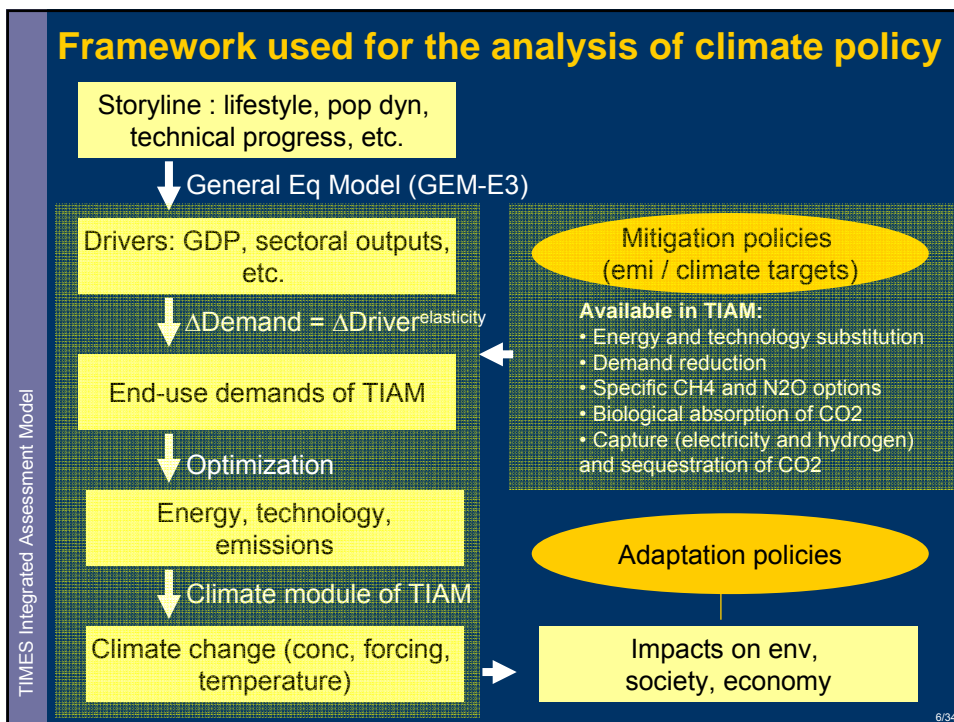
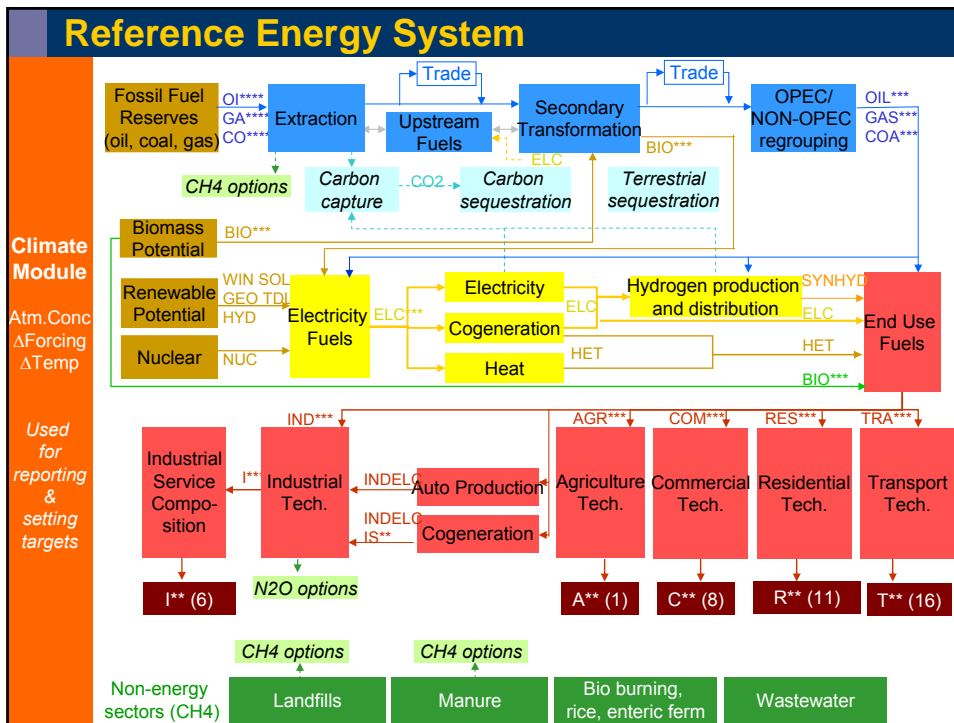
## 15 regions + OPEC/Non-OPEC

<p>Africa*</p> <p>Australia-New Zealand</p> <p>Canada</p> <p>Central and South America*</p> <p>China</p>	<p>Eastern Europe</p> <p>Former Soviet Union</p> <p>India</p> <p>Japan</p> <p>Mexico</p>	<p>Middle-East*</p> <p>Other Developing Asia*</p> <p>South Korea</p> <p>United States</p> <p>Western Europe</p>
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\* OPEC and Non-OPEC countries are separated in primary and secondary sectors → oil production strategies and oil price control by OPEC countries



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## Periods, Demands, Sectoral description

## Periods

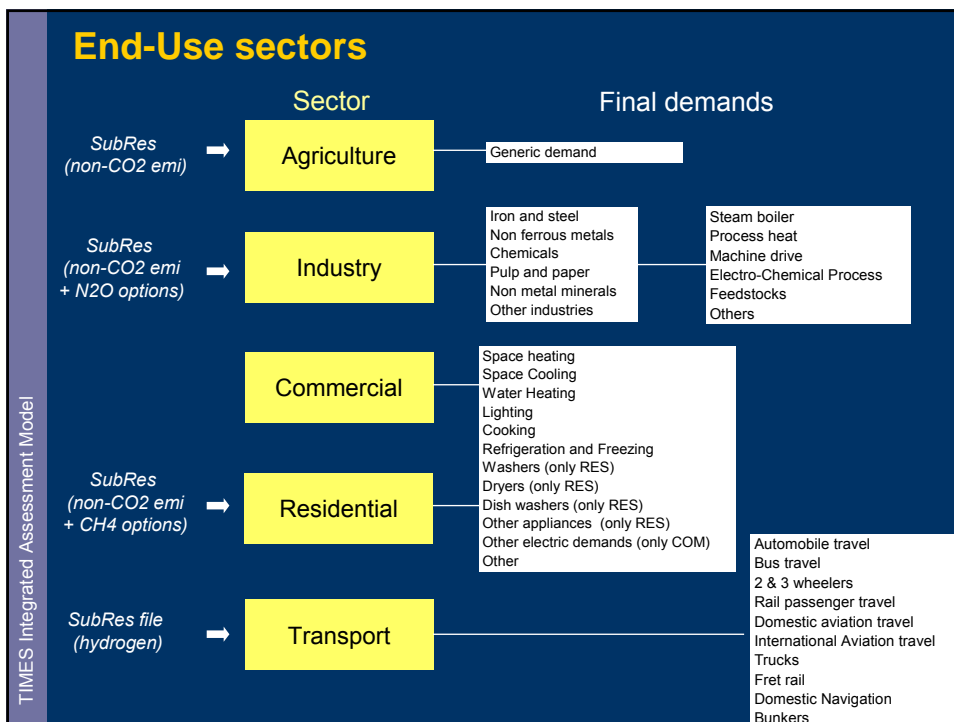
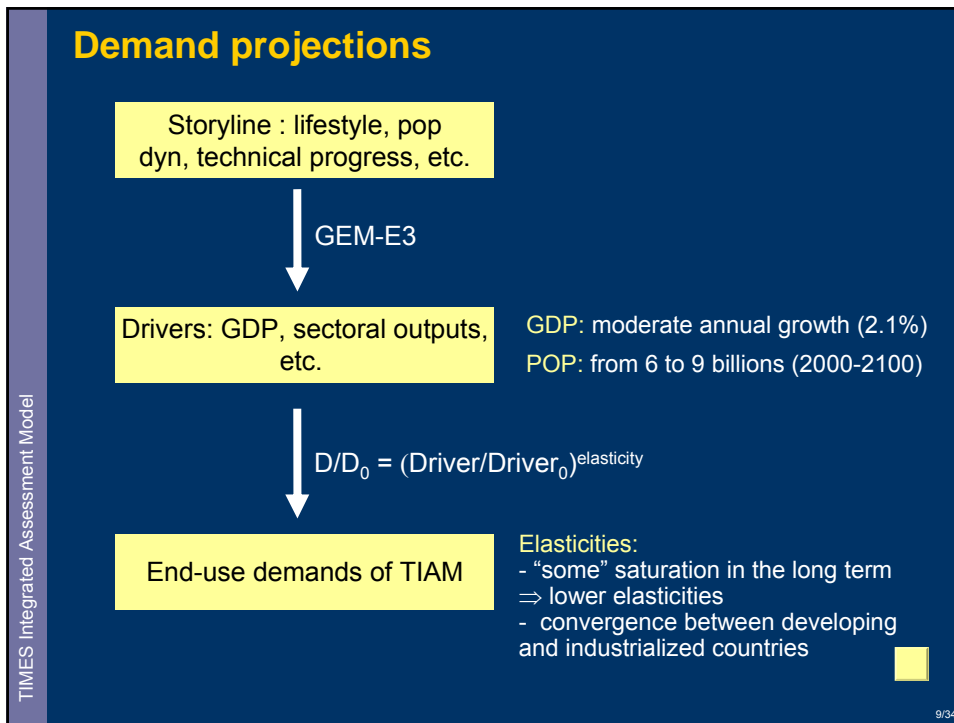
BaseYear	Start	Mid	End	Lnth
1998	1998	2000	2002	5
2	2002	2005	2008	6
3	2008	2015	2021	13
4	2022	2030	2039	18
5	2040	2050	2060	21
6	2061	2070	2080	20
7	2081	2090	2100	20

Period 7 2090 (2081 To 2100)  
 Period 6 2070 (2061 To 2080)  
 Period 5 2050 (2040 To 2060)  
 Period 4 2030 (2022 To 2039)

\* More rows will be added as you start editing last row

7 periods (stochastic analysis)  
 Variable length

Basecase, 15 regions,  
 endogenous trade  
 = 25 minutes (1.8 Ghz, Cplex  
 9.1, Barrier algorithm, 330 000  
 equations)



## Base year (2000) information

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 regional statistics (installed capacities and resource potentials)

## Primary and secondary energy

### Fossil resources and extraction

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

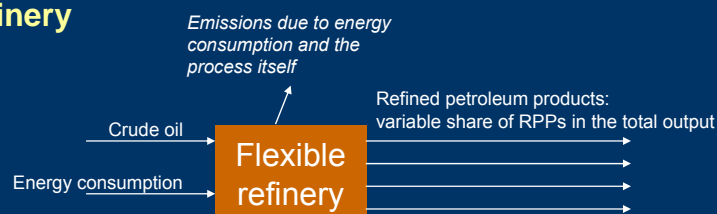
Eg. Oil: 21 (conventional, oil sands, located, enhanced recovery, new discovery...)

Gas: 9 (conventional, unconventional, not connected)

Coal: 4 (browncoal, hardcoal, located, new discovery)

► Reviewed by IER (Uwe Remme)

### Refinery



## Primary and secondary energy

### Renewable and other

Geothermal: Shallow, deep and very deep

Hydro: Dam and run-of-river  
WEC technical potential + 25% of the theoretical potential

Wind: Four types of plants (different costs)  
Equivalent to 10% of the potential provided by IPCC-TAR  
~ WEC assuming 4% of the land area

Solar

Nuclear: Basecase = 109 EJ 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)

### Sources of data

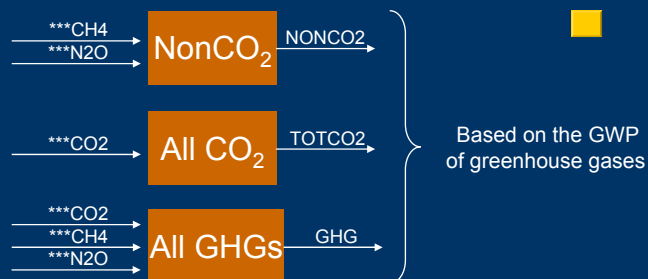
IEA-ETP, World Energy Council, IPCC-TAR, US Geological Survey

## Endogenous trade

Endogenous trade of coal, crude oil, gas, liquefied gas (*reviewed by IER*)  
⇒ price and amount of traded energy are endogenous  
⇒ the impact on trade of environmental policies is taken into account

Endogenous trade of CO<sub>2</sub> (or GHG) permits

The user can choose which gases/energy commodity and which regions are included in trade (eg. only CO<sub>2</sub>, all GHGs, only some countries)



## Electricity sector (cogen and autoprod not shown)

<i>Regional templates</i>	16 existing power plants
<i>SubRes NewTech</i>	51 new power plants
<i>SubRes Sequestration</i>	10 power plants with CO <sub>2</sub> capture

The price of electricity generated by power plants with CO<sub>2</sub> capture ~ 50% higher than the electricity price generated by power plants without capture.

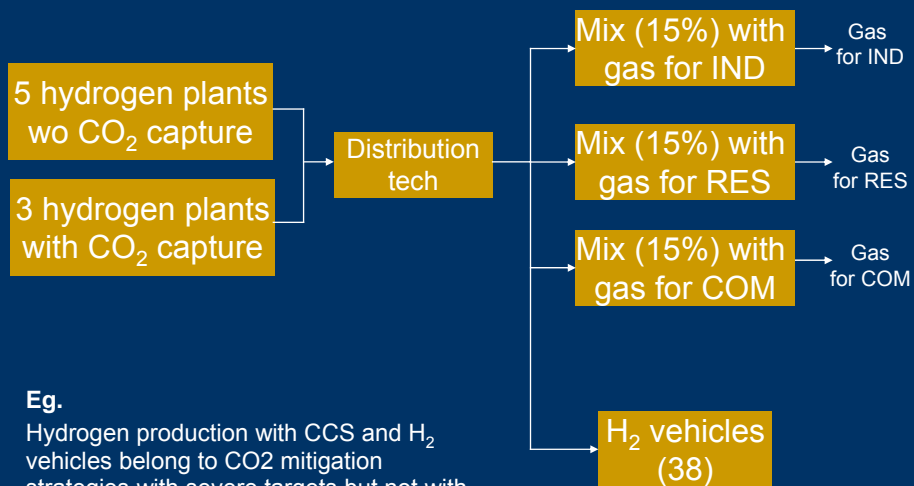
### Remarks

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)

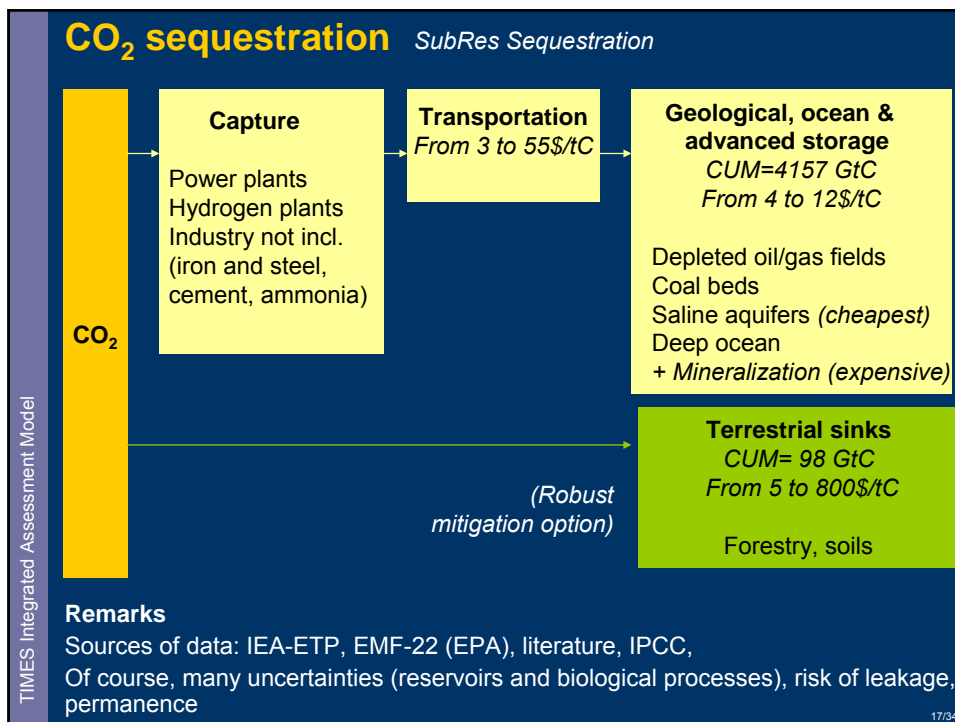
## Hydrogen sector *SubRes Hydrogen*



### Eg.

Hydrogen production with CCS and H<sub>2</sub> vehicles belong to CO<sub>2</sub> mitigation strategies with severe targets but not with moderate targets





## CH<sub>4</sub> and N<sub>2</sub>O (energy and non-energy – EMF21&22)

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	% modeled CH <sub>4</sub> emissions in 2000		Abatement technologies	
	TIAM	EMF	EMF	TIAM
<i>Non-energy emissions</i>				
Manure	4%	5	4	
Landfill	13%	11	11	
Wastewater	10%	0	0	
Biomass burning, Enteric Fermentation, Rice	46%	0	0	
<i>Energy emissions</i>				
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	
<b>Total</b>	<b>100 %</b>	<b>63</b>	<b>41</b>	

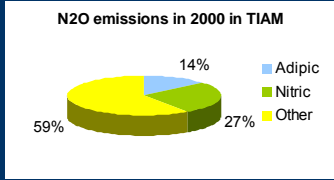
(regional variations)

**Examples of options**  
Catalytic oxidation of methane in coal mines, anaerobic digestion of wastes (with gas recovery), flaring instead of venting (oil extraction), etc.  
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)

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# CH<sub>4</sub> and N<sub>2</sub>O (energy and non-energy – EMF22)

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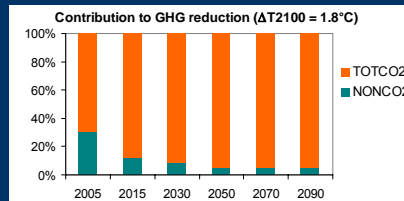
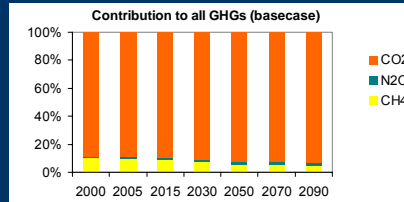
## Examples of options for N2O

Different types of catalytic reduction, thermal destruction

### Remarks

Some no-regret CH<sub>4</sub> mitigation options penetrate in base case (mostly production of “cheap” gas or electricity) - Also observed by US-EPA using MARKAL for the US

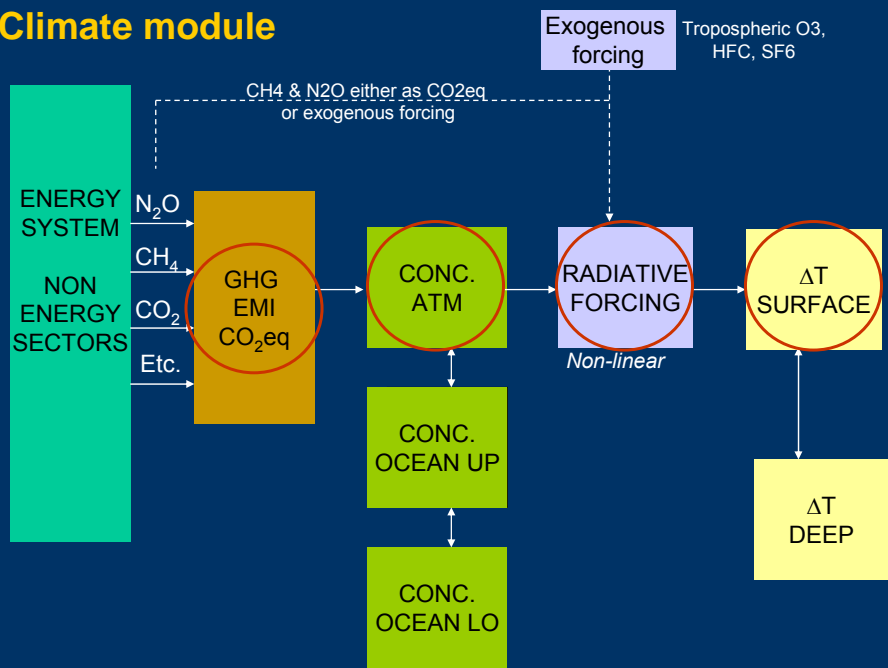
CH<sub>4</sub> and N<sub>2</sub>O options help for GHG reduction in the short term



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# Climate module

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## Examples of analyses

MARKAL previous version of the model  
Integration of climate damages and analysis of World cooperative and non-cooperative strategies

### EMF-22

- 1) Stochastic analysis of climate policies
  - ▶ Long term concentration / temperature targets
- 2) Transition policies (to do)
  - ▶ Simulate policies that could be applied in 2010-2040  
Eg. *sectoral caps and trade, taxes and/or subsidies on commodities and/or technologies, technology standards (car efficiency, building shell efficiency), portfolio standards (emission per kWh of electricity produced)*

## Examples of analyses

### Other

- 1) Nuclear policies (exploratory analysis)
  - ▶ Potential role of nuclear energy in climate policies by 2100
- 2) Transport policies (exploratory analysis)
  - ▶ CO<sub>2</sub> tax up to 1000\$/tCO<sub>2</sub> in 2100
  - ▶ Biofuels, demand reduction, hydrogen with CCS (late)
  - ▶ Small contribution of transportation to the total CO<sub>2</sub> reduction
  - ▶ Small impact of high oil price on strategies under severe climate policies
  - ▶ Max reduction of CO<sub>2</sub> in 2050 (all sectors) vs. 2000 = ratio of 2
- 3) GICC, TOCSIN

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Appendices

## 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 <sup>a</sup> , 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 <sup>b</sup> , 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 <sup>c</sup> , Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam
WEU	Austria, Belgium, Denmark, Finland, France <sup>d</sup> , Germany, Gibraltar, Greece, Greenland, Iceland, Ireland, Italy <sup>e</sup> , Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

<sup>a</sup>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.

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

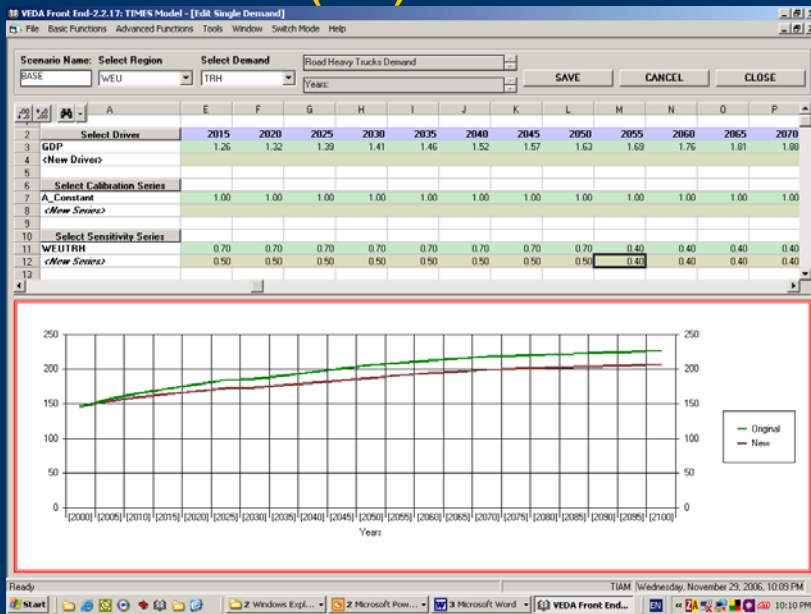
<sup>c</sup>Included: Afghanistan, Eastera, Fiji, French Polynesia, Kiribati, Maldives, New Caledonia, Papua-New-Guinea, Samoa, Solomon Islands, Vanuatu. Excluded due to lack of data: American Samoa, Cambodia, Christmas Island, Cook Islands, Laos, Macau, Mongolia, Nauru, Niue, Pacific Islands, Tonga,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

<sup>d</sup>Includes Monaco.

<sup>e</sup>Includes San Marino and Vatican City

<sup>f</sup>Includes Liechtenstein

## Demand module (VFE)



## Example of endogenous of trade (VFE)

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Commodity: **NATNGA**  
 Commodity Description: **Natural gas**

Trade Link:  Uni-Directional  
 Bi-Directional  
 Market

**IMPORTERS**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1																		
2			AFR	AUS	CAN	CHI	CSA	EEU	FSU	GLB	IND	JPN	MEA	MDX	DDA	SKO	USA	WEU
3																		
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EXPORTERS

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## CH4 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

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## CH4 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

<i>Not modeled</i>	<i>P&amp;T - Compressors-Altering Start-Up Procedure during Maintenance</i>
	<i>Prod-D I&amp;M (Chemical Inspection Pumps)</i>
	<i>Prod-D I&amp;M (Enhanced)</i>
	<i>Prod-D I&amp;M (Offshore)</i>
	<i>Prod-D I&amp;M (Onshore)</i>
	<i>Installation of Electric Starters on Compressors (Production)</i>
	<i>Installing Plunger Lift Systems In Gas Wells</i>
	<i>Portable Evacuation Compressor for Pipeline Venting (Production)</i>
	<i>Reducing the Glycol Circulation Rates in Dehydrators (Production)</i>
	<i>Surge Vessels for Station/Well Venting (Production)</i>
	<i>Fuel Gas Retrofit for Blowdown Valve</i>
	<i>Reducing the Glycol Circulation Rates in Dehydrators (P&amp;T)</i>
	<i>P&amp;T-D I&amp;M (Compressor Stations)</i>
	<i>P&amp;T-D I&amp;M (Compressor Stations: Enhanced)</i>
	<i>P&amp;T-D I&amp;M (Enhanced: Storage Wells)</i>
	<i>P&amp;T-D I&amp;M (Pipeline: Transmission)</i>
	<i>P&amp;T-D I&amp;M (Wells: Storage)</i>
	<i>Installation of Flash Tank Separators (P&amp;T)</i>
	<i>Portable Evacuation Compressor for Pipeline Venting (P&amp;T)</i>
	<i>Static-Pacs on reciprocating compressors (P&amp;T)</i>
	<i>Surge Vessels for Station/Well Venting (P&amp;T)</i>

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## N2O options

### Adipic Acid

ICH4ADI01	Thermal Destruction
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### 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)

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## End-use demands (1/2)

	Code	Unit
<b>Transportation segments (15)</b>		
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
<b>Residential segments* (11)</b>		
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)

<b>Commercial segments* (8)</b>		
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
<b>Agriculture segment (1)</b>		
Agriculture	AGR	
<b>Industrial segments** (6)</b>		
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
<b>Other segment (1)</b>		
Other non specified energy consumption	ONO	PJ/year



## Drivers used to build energy service demands in TIAM (1/2)

DEMAND	DRIVER	
<b>Transportation</b>	<b>All regions</b>	
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	
<b>Residential</b>	<b>All regions after 2050 + Non-OECD before 2050</b>	<b>OECD regions before 2050</b>
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

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

DEMAND	DRIVER	
<b>Commercial</b>	<b>All regions</b>	
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	
<b>Agriculture</b>	SPROD-Agriculture	
<b>Industry</b>	<b>All regions</b>	
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

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