



## Modeling of fossil resources and trade in the TIAM model - Results of the base scenario

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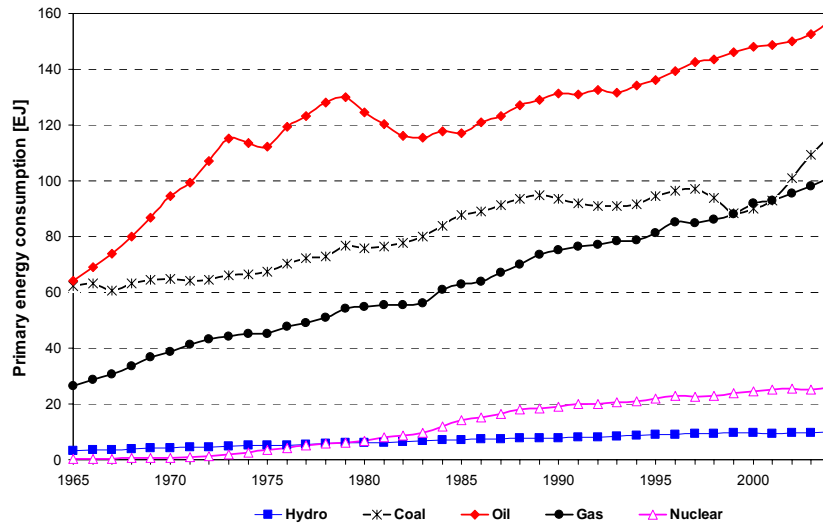


## Overview

- Modeling of the fossil reserves and resources in the TIAM model
- Global trade structure for fossil fuels between world regions and introduction of transport costs
- Results of base scenario



## Global primary energy supply



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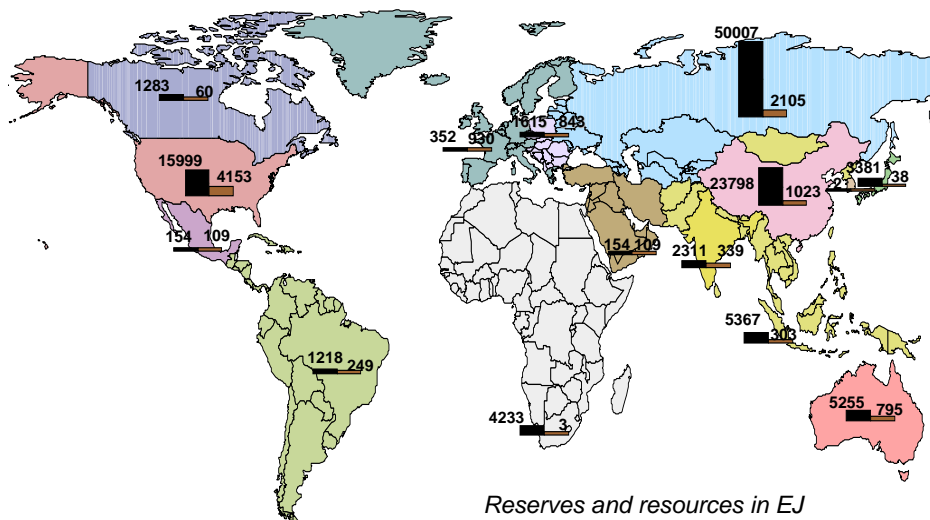
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## Global distribution of coal and lignite



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## Hard coal

- Reserves and resources (based on the end of 1997):

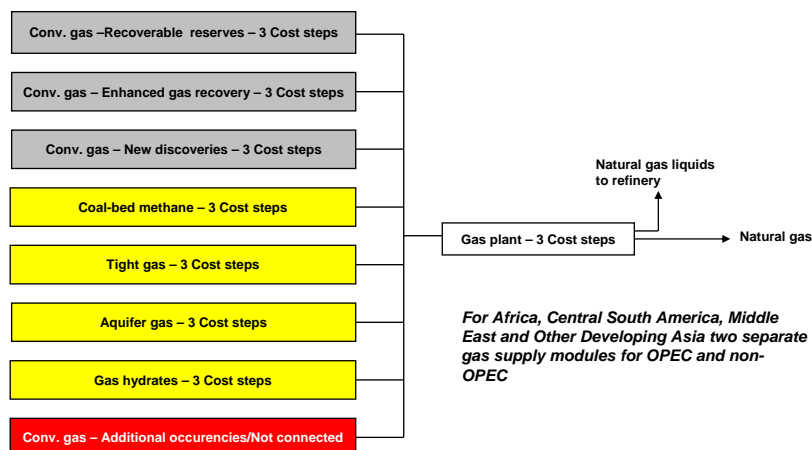
EJ	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU	Total			
<b>Reserves [EJ]</b>	1243	1605	90	2523	370	298	4597	2196	9	35	22	170	2	6135	46	<b>19342</b>			
<b>Resources [EJ]</b>	2989	3650	1193	21275	847	1317	45410	114	3872	119	48	5197	0	9864	306	<b>96201</b>			
<b>Average heating value [MJ/kg]</b>	22.86	23.45	-	27.84	21.1	20.52	17.58	19.34	-	20.8	22.8	-	23.5	-	23.5	25.2	-	-	<b>19.05</b>
	24.91	26.38	-	-	-	27.55	24.91	23.45	-	26.67	-	23.45	-	-	27.55	-	-	-	<b>27.55</b>

- Supply costs (reserves and resources modeled with only one cost step each):

\$/GJ	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Reserves	<b>1.03</b>	<b>1.06</b>	<b>1.87</b>	<b>1.36</b>	<b>0.96</b>	<b>1.53</b>	<b>0.86</b>	<b>1.60</b>	<b>3.65</b>	<b>4.00</b>	<b>1.87</b>	<b>1.18</b>	<b>3.65</b>	<b>1.31</b>	<b>3.65</b>
Resources	<b>1.37</b>	<b>1.40</b>	<b>2.20</b>	<b>1.70</b>	<b>1.30</b>	<b>1.87</b>	<b>1.20</b>	<b>1.94</b>	<b>4.01</b>	<b>4.34</b>	<b>2.20</b>	<b>1.53</b>	<b>4.01</b>	<b>1.66</b>	<b>4.01</b>



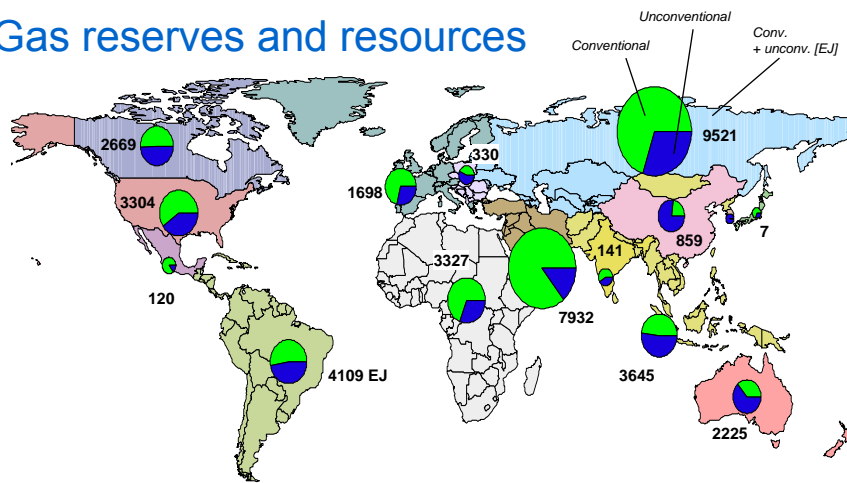
## Modeling of gas supply in TIAM



- Addition of new unconventional resources coal-bed methane, CBM, tight gas and aquifer gas



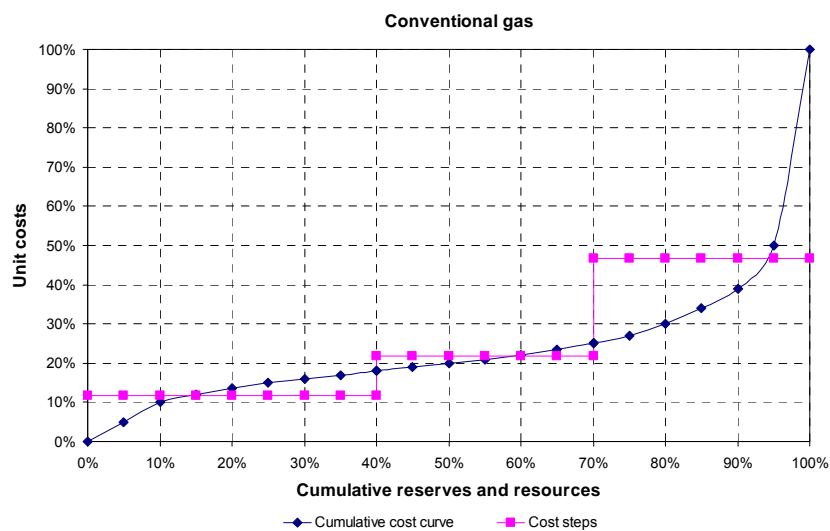
## Gas reserves and resources



Conventional [EJ]		Unconventional reserves + resources [EJ]			Total [EJ]	Gas hydrates resources [EJ]	Gas production 2004 [EJ]
Reserves	Resources	Coal-bed methane	Tight gas	Aquifer gas			
12673	5256	2827	1694	17441	39890	47400	88



## Logistic cost curves



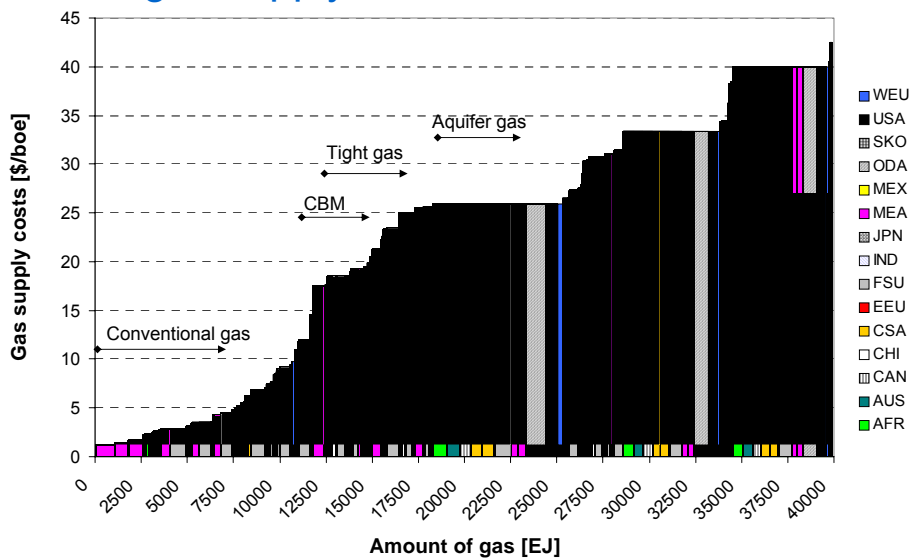


## Supply cost ranges of natural gas

\$/GJ		AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
		Min	0.4	1.8	1.3	0.4	0.4	0.6	0.5	0.4	0.6	0.2	1.3	0.4	0.6	1.4
Max	0.5	2.1	1.8	0.6	0.5	1.2	0.8	0.6	1.2	0.3	1.8	0.5	1.2	1.6	1.2	
EGR	Min	3.3	5.4	5.8	3.4	3.1	5.1	3.9	3.4	5.1	2.9	5.8	3.3	5.1	4.4	5.1
	Max	4.6	6.8	7.1	4.8	4.4	6.4	5.3	4.8	6.4	4.3	7.1	4.6	6.4	5.8	6.4
Undisc. Resources	Min	0.9	3.9	3.0	0.9	0.8	1.6	1.1	0.9	1.6	0.5	3.0	0.9	1.6	2.9	1.6
	Max	1.2	4.9	4.7	1.4	1.0	3.3	2.0	1.4	3.3	0.7	4.7	1.2	3.3	3.4	3.3
Coal-bed methane	Min	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
	Max	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Tight gas	Min	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
	Max	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Gas hydrates	Min	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
	Max	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2
Aquifer gas	Min	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
	Max	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7

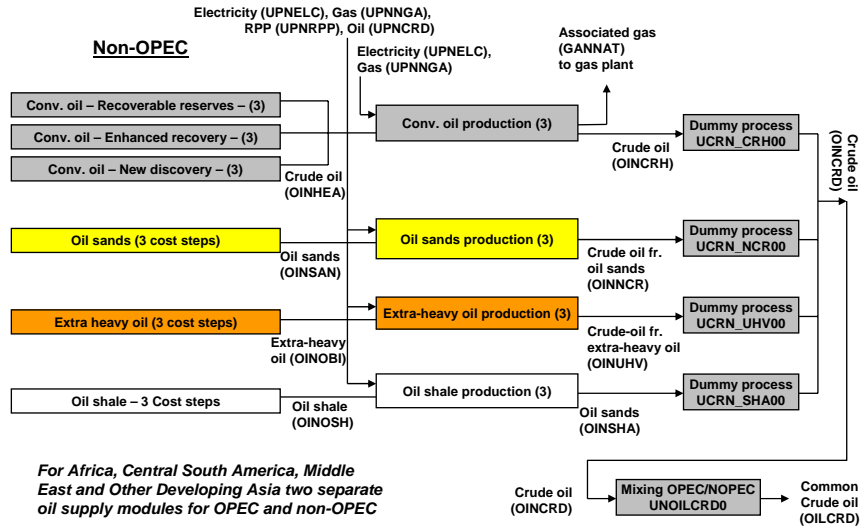


## Global gas supply cost curve

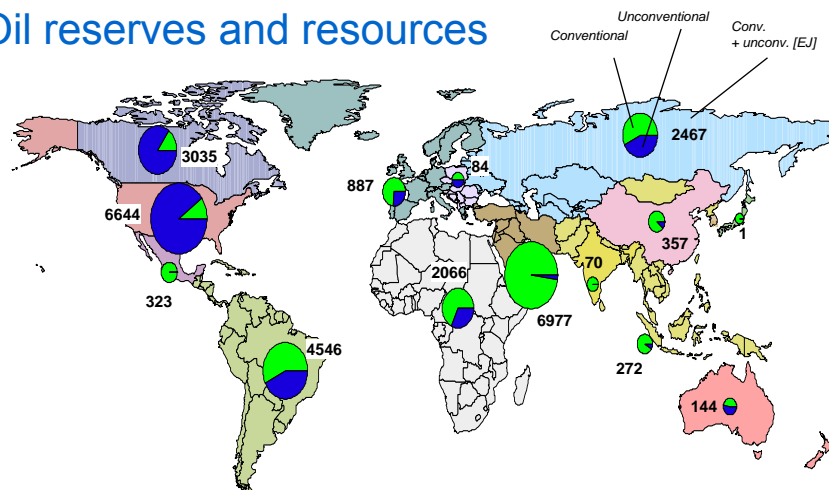




## Modeling of oil supply in TIAM



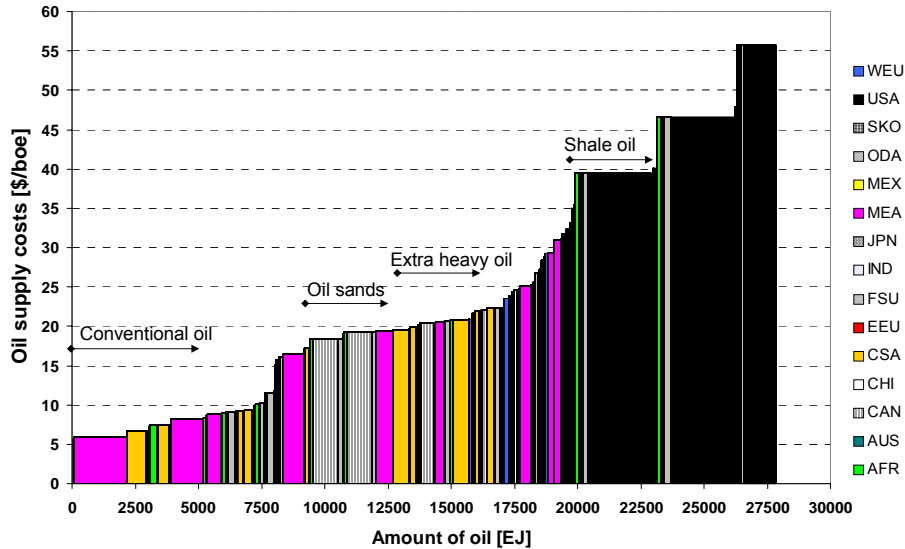
## Oil reserves and resources



Conventional [EJ]		Unconventional reserves + resources [EJ]			Total [EJ]	Production 2004 [EJ]
Reserves	Resources	Tar sand	Extra heavy oil	Shale oil		
11 776	3 618	3 117	1 616	7 745	27 873	161



## Global oil supply cost curve



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## Comparison of old and new reserve and resource data

Region	Gas [EJ]				Oil [EJ]				Coal [EJ]			
	Conventional		Unconventional		Conventional		Unconventional		Hard coal		Lignite	
	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
AFR	1,326	2,215	2,002	0	1,450	1,528	616	445	4,232	8,868	2	47
AUS	365	193	1,861	53	72	44	72	208	5,255	6,066	795	5,613
CAN	749	2,234	1,919	79	533	248	2,501	8,266	1,283	1,079	60	821
CHI	200	216	658	59	318	361	39	271	23,798	7,423	1,022	6,242
CSA	968	1,792	3,141	116	2,749	1,855	1,798	5,596	1,218	1,162	249	1,514
EEU	82	91	248	25	43	24	41	14	1,615	1,717	834	2,242
FSU	5,552	9,201	3,966	2,111	1,434	1,909	1,033	3,059	50,007	11,040	2,105	15,549
IND	86	124	56	28	70	64	0	0	2,311	9,234	377	254
JPN	5	10	3	2	1	1	0	0	3,881	108	0	0
MEA	5,527	5,924	2,401	668	6,880	6,918	97	3,721	154	34	108	33
MEX	104	84	15	0	323	590	0	158	69	102	3	42
ODA	759	4,025	2,896	192	250	229	22	128	5,367	7,643	303	7,855
SKO	0	0	2	0	0	0	0	0	2	5	0	0
USA	1,291	1,819	2,011	181	598	1,107	6,046	4,941	15,999	31,237	4,154	36,736
WEU	914	1,071	783	0	673	325	214	306	352	2,025	930	3,508
<b>Total</b>	<b>17,928</b>	<b>28,998</b>	<b>21,962</b>	<b>3,515</b>	<b>15,394</b>	<b>15,202</b>	<b>12,479</b>	<b>27,113</b>	<b>115,541</b>	<b>87,745</b>	<b>10,944</b>	<b>80,456</b>

- Total recoverable deposits (reserves+resources, new data based on the end of 1997)
- Unconventional gas without gas hydrates
- **Natural gas:** New conventional resources lower, new unconventional resources higher mainly due to aquifer gas
- **Oil:** Unconventional resources for extra-heavy oil and tar sands are lower in the new data set
- **Coal:** Larger differences caused by different resource numbers for China, FSU and USA

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## Review and update of global energy trade

- Review and update:
  - i. Expanded trade links for crude oil, pipeline gas and LNG
  - ii. Introduction of trade for hard coal (sum of steam and coking coal) previously modeled as external imports/exports
  - iii. Introduction of trade in petroleum products (distillates, gasoline, heavy fuel oil, naphtha); otherwise refineries in oil-producing regions are not utilized, since only crude oil but not the petroleum products can be exported
  - iv. Introduction of transport costs for inter-regional energy trade:
    1. Modeled as variable costs for coal, crude oil and petroleum products
    2. Modeled through capacities (existing and new) for pipeline gas and LNG
- New data set summarized in Excel files with linked scenario sheet for import into VEDA-FE
  - i. Trade\_coal.xls
  - ii. Trade\_gas.xls, Trade\_lng.xls
  - iii. Trade\_oil.xls, Trade\_oildst.xls, Trade\_oilgsl.xls, Trade\_oilhfo.xls, Trade\_oilnap.xls



## Existing natural gas pipelines between world regions

Origin		Destination		Capacity	Major Pipelines
Region	Country	Region	Country	P/a	
FSU	Russia	WEU	Finland	401	Finland Connector
	Belarus	EEU	Poland	1242	Yamal Pipeline
FSU	Ukraine	EEU	Poland	361	
	Ukraine	EEU	Slovakia	4327	Brotherhood pipeline
	Ukraine	EEU	Hungary	601	Shebelynka-Izmail Pipeline
	Ukraine	EEU	Romania	1322	
FSU		EEU	Total	7853	
EEU	Poland	WEU	Germany	1082	Yamal Pipeline
	Czech Republic	WEU	Germany	2244	Transgas Pipeline
	Slovakia	WEU	Austria	2003	Trans Austria Gaspipeline (TAG)
EEU		WEU	Total	5329	
WEU	Austria	EEU	Slovenia	160	SOL Pipeline
	Austria	EEU	Hungary	160	Hungary Austria Gaspipeline (HAG)
WEU		EEU	Total	320	
AFR	Algeria	WEU	Spain	441	Maghreb-Europe Gas Pipeline (MEG)
	Algeria	WEU	Italy	1162	Transmediterranean Pipeline (Transmed)
	Libya	WEU	Italy	240	Green Stream Pipeline
AFR		WEU	Total	1843	
FSU	Russia	MEA	Turkey	641	Blue Stream Pipeline
MEA	Iran	FSU	Azerbaijan	881	Baku-Astara Pipeline
EEU	Bulgaria	MEA	Turkey	441	Shebelynka-Izmail Pipeline
CAN	Canada	USA	USA	6868	
USA	USA	MEX	Mexico	1482	



## Pipeline gas trade

		Destination														
		AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Origin	AFR															1676
	AUS															
	CAN														3768	
	CHI															
	CSA															
	EEU															3590
	FSU							5245			947					
	IND															
	JPN															
	MEA															
	MEX															
	ODA															
	SKO															
	USA											406				
	WEU															

- Pipeline gas trade in PJ for the year 2005
- Trade statistics for 2000 and 2005 as lower bounds
- Grey cells indicate trade links modeled in TIAM
- Empty cells indicate new pipelines not yet existing



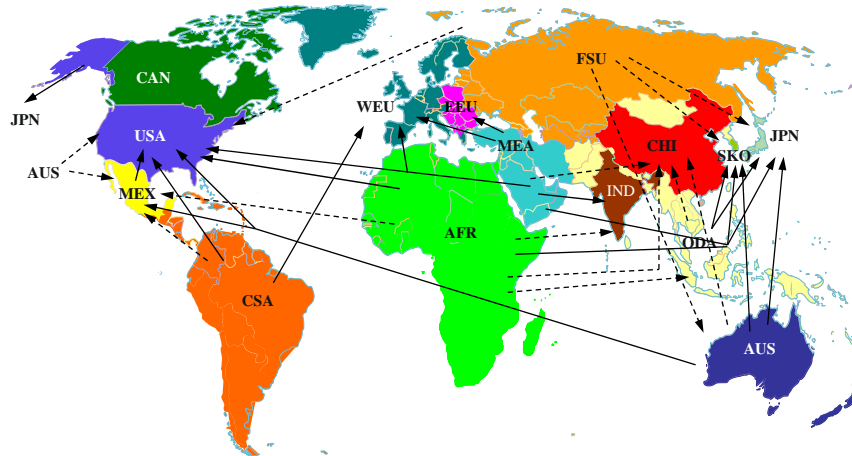
## LNG gas trade

		Destination														
		AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Origin	AFR									3	196					
	AUS								6	523			16	46		
	CAN															
	CHI															
	CSA														498	26
	EEU															
	FSU															
	IND															
	JPN															
	MEA								236	655			6	574	6	264
	MEX															
	ODA									1803				588	10	6
	SKO															
	USA									73						
	WEU															

- LNG gas trade in PJ for the year 2005
- Trade statistics for 2000 and 2005 as lower bounds
- Grey cells indicate trade links modeled in TIAM



## LNG gas trade



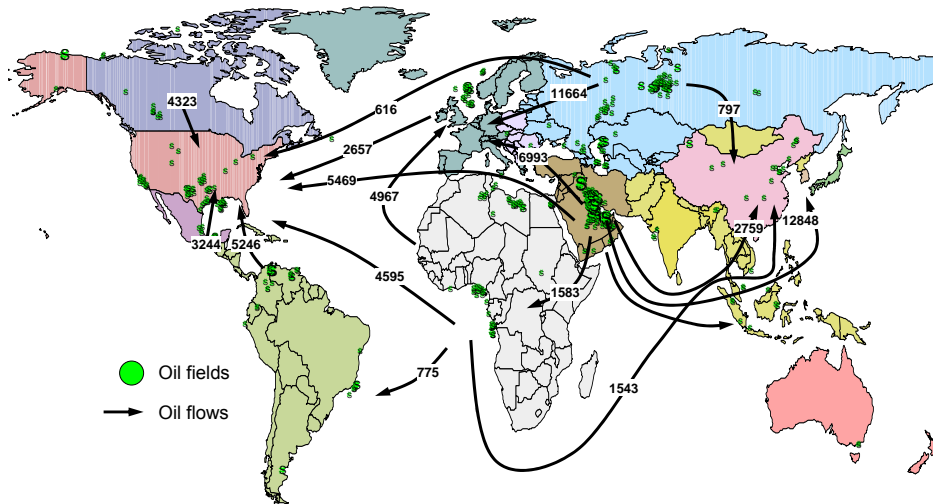
## Existing LNG liquefaction and regasification

Import		Export	
Import countries	Import capacity	Export countries	Export capacity
Belgium	4.5	Algeria	31.9
Dominican Republic	2.75	Australia	22.0
France	15.5	Brunei	9.9
Greece	2.6	Egypt	16.8
India	6.9	Indonesia	40.6
Italy	3.3	Libya	1.2
Japan	259.7	Malaysia	32.6
Portugal	5.5	Nigeria	13.1
Puerto Rico	0.96	Oman	15.2
South Korea	58.5	Qatar	35.2
Spain	33.6	Trinidad&Tobago	20.4
Taiwan	10.28	United Arab Emirates	7.9
Turkey	5.2		
UK	4.4		
USA	42.1	USA	1.9
<b>Total</b>	<b>455.8</b>	<b>Total</b>	<b>247.7</b>

- Capacities at the end of 2005 in bcm/yr (billion cubic meter per year)



## Global oil trade flows



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## Crude oil trade

		Destination														
		AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Origin	AFR			456	1683	574	17		752	310		9	983	195	5436	5247
	AUS				37					124				185	31	
	CAN									13					4406	
	CHI			4										47	52	
	CSA			229	162				126	4		5	4	5556	570	
	EEU															
	FSU	22			869	131	1547			103		4	110	47	1033	1113
	IND															9
	JPN				48											4
	MEA	1642	247	312	2969	114	2		1810	9320		22	10534	3955	5119	6862
	MEX			70	199								65		3135	351
	ODA		934	9	736				160	1070				396	212	7
	SKO															
	USA					705				183				11		
	WEU			932	17									12	1873	

- Crude oil trade in PJ for the year 2005
- Trade statistics for 2000 and 2005 as lower bounds
- Grey cells indicate trade links modeled in TIAM

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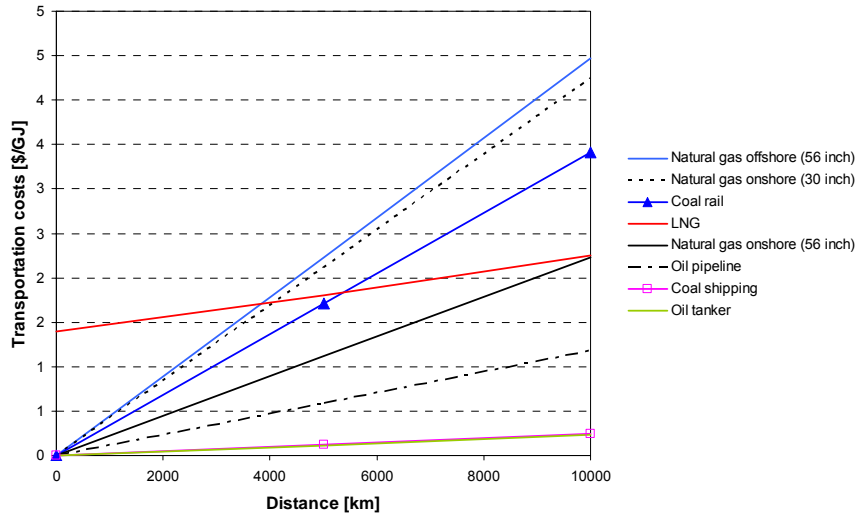
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### Specific transport costs



### Example: Calculation of LNG shipping costs (1)

		Destination														
		AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Origin	AFR				10573				6937	10653			8028	10357	3463	400
	AUS			2424						2796		7326			2934	7326
	CAN															
	CHI															
	CSA											2220				2272
	EEU															
	FSU		4653							1725				1548	5891	
	IND															
	JPN															
	MEA								1365	5958				6093	11218	4512
	MEX															
	ODA				1872					2746					2888	
	SKO															
	USA															
WEU																

- Shipping distances between world regions in Nautic miles



## Example: Calculation of LNG shipping costs (2)

Parameter	Value	Unit
One way distance (d)	10000	km
Maintenance time per year ( $t_{main}$ )	20	days
Speed (s)	23	km/h
Time for loading and unloading per trip ( $t_{load}$ )	48	h
Number of trips per year ( $n_{trip}$ )	9	per year
Capacity of the tanker ( $cap_{tanker}$ )	135000	m <sup>3</sup> LNG
Loading factor (lf)	0.98	
Total transport capacity in one year ( $cap_{tot}$ )	1193860	m <sup>3</sup> LNG/a
FOM costs tanker (fom)	4	%
Investment costs tanker (inv)	200,000,000	\$ per tanker
Lifetime (life)	20	a
Discount rate (dr)	6	%
Annuity (annuity)	17,436,911	\$/a
Total annual costs ( $cost_{annual}$ )	25,436,911	\$
Specific transport costs ( $cost_{spec}$ )	21.31	\$/m <sup>3</sup> LNG

- Grey cells in table are input data, white cells are calculated values

- Formulas for calculating specific transport costs:

$$n_{trip} = \frac{24 \cdot (365 - t_{main})}{2 \cdot d - t_{load} \cdot s} \cdot s$$

*Number of trips per year*

$$cap_{tot} = lf \cdot cap_{tanker} \cdot n_{trip}$$

*Total transport capacity in one year*

$$cost_{spec} = \frac{annuity + fom \cdot inv}{cap_{tot}}$$

*Specific annual transport costs*

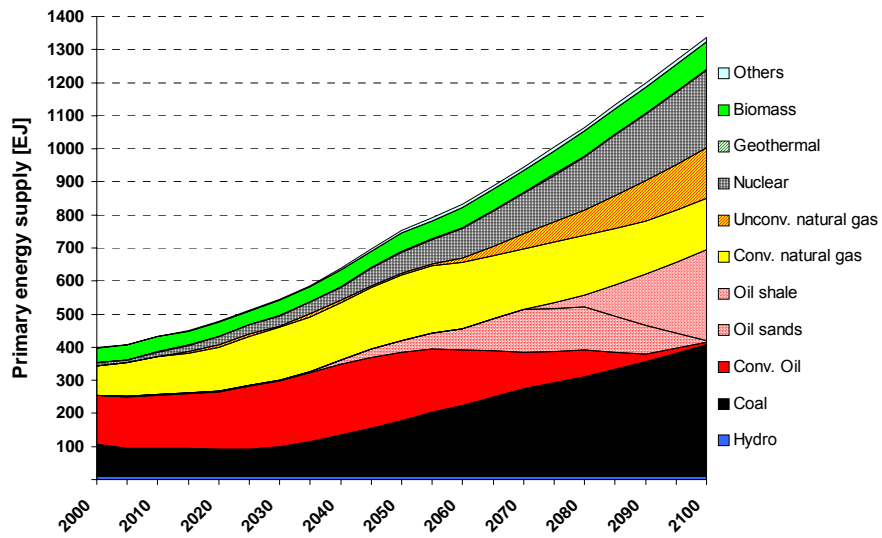


## Results of base case

- Base scenario (BAS) oriented towards the IPCC B2 scenario:
  - i. World GDP:
    1. 2000: 37 trillion US\$2000, 2100: 235 trillion US\$2000 -> average annual growth rate of 1.8 %
  - ii. World population:
    1. 2000: 6 billion, 2100: 9.8 billion
- Nuclear and renewables:
  - i. slow growth of nuclear up to 2040, more rapid growth afterwards
  - ii. coal and gas dominant energy carriers after 2050, low use of renewables



## Total primary energy supply



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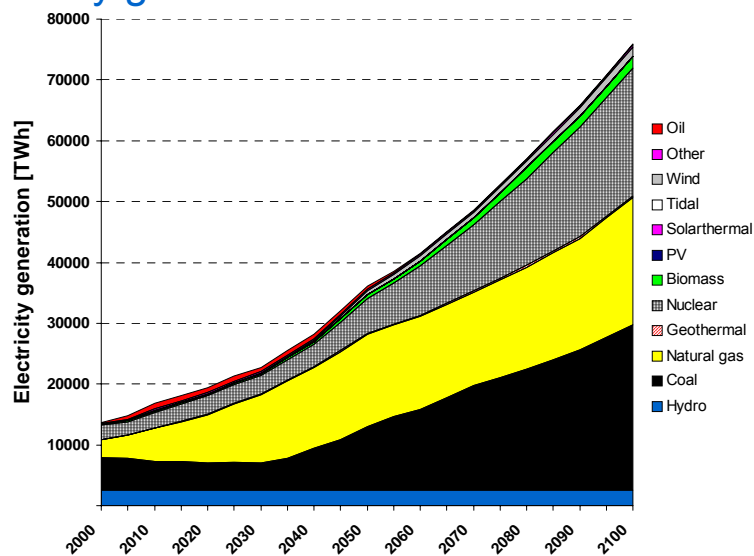
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## Electricity generation

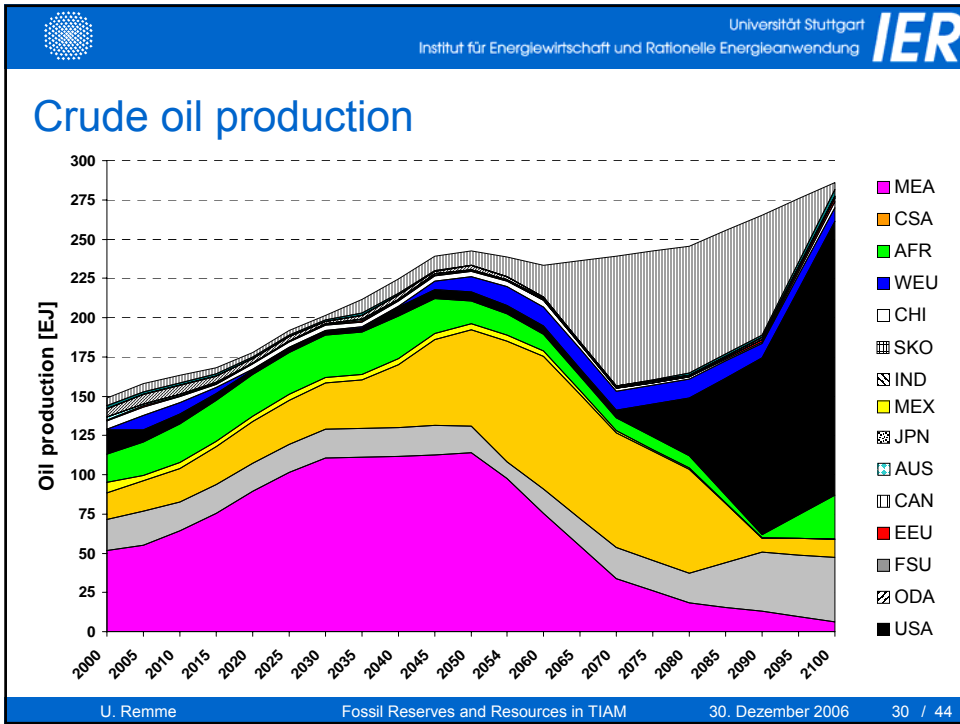
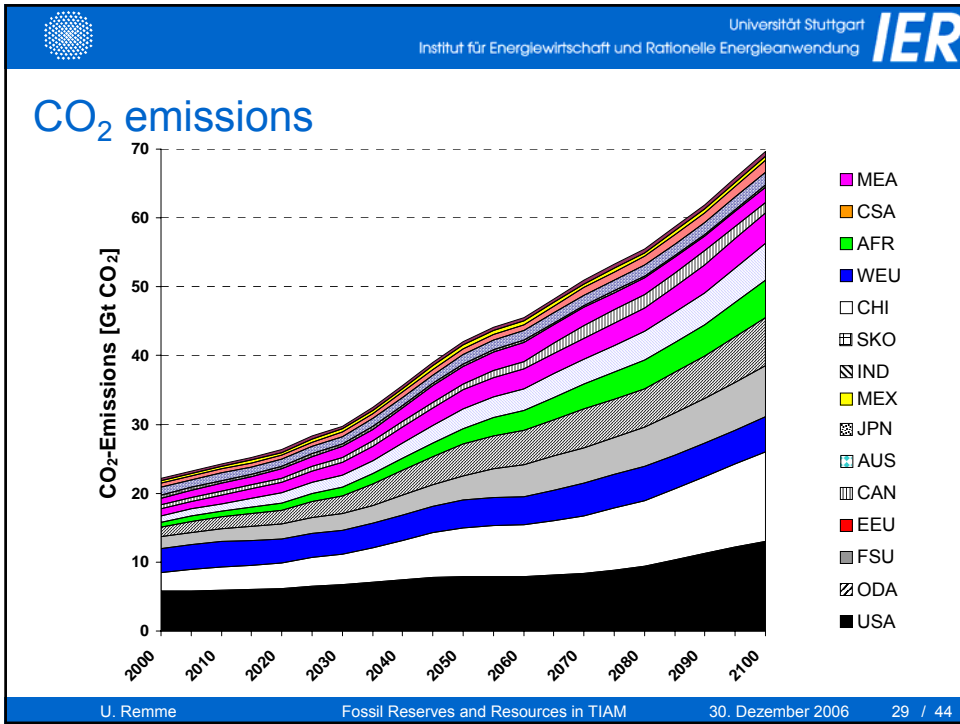


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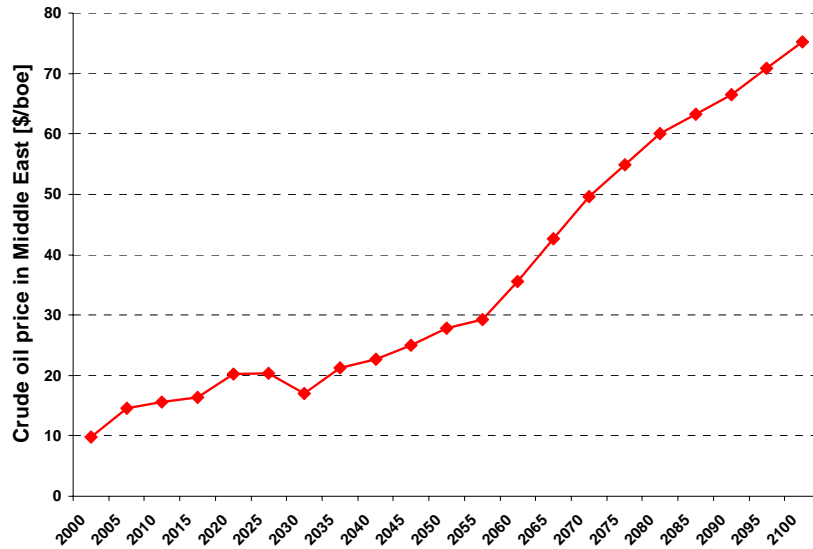
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## Crude oil price



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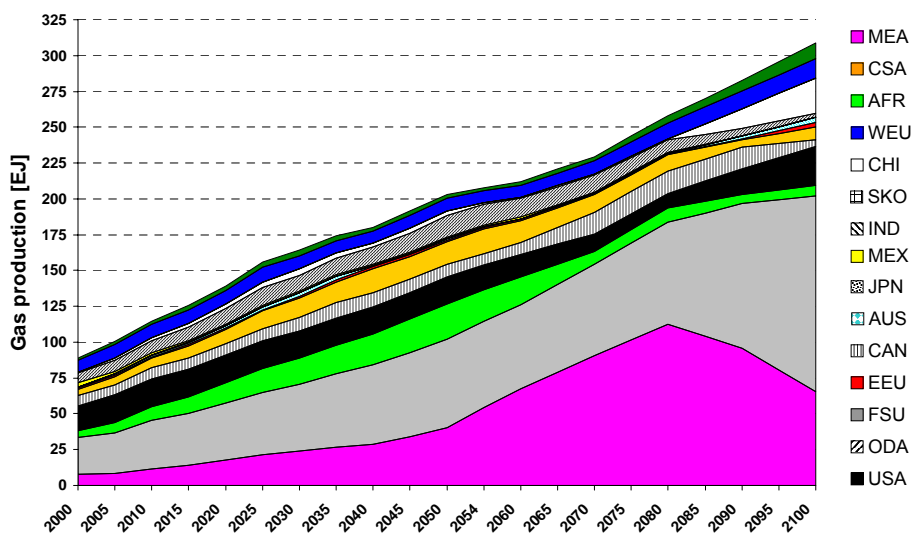
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## Natural gas production



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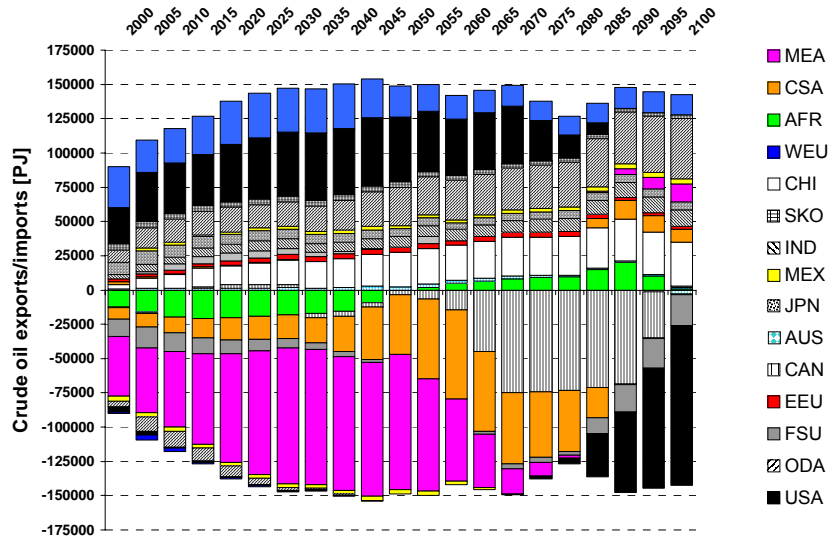
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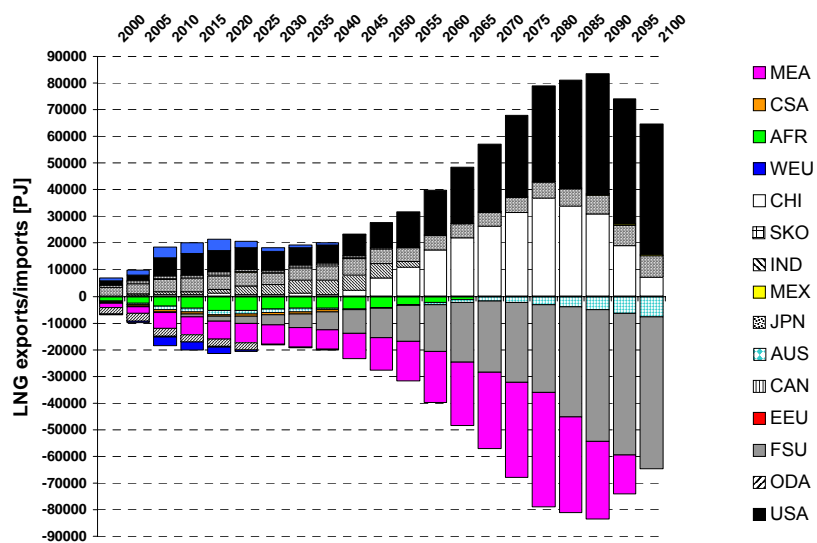
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## Results: Crude oil trade

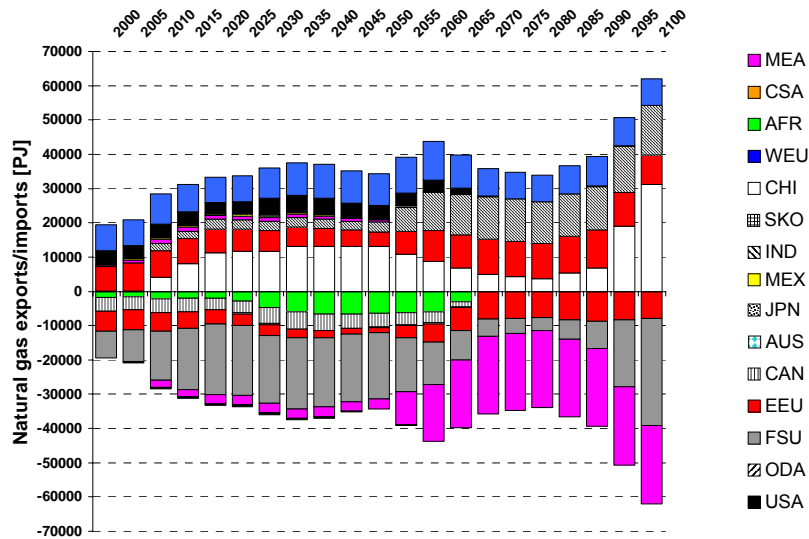


## Results: LNG trade





## Results: Natural gas pipeline trade



## Summary (1)

- Review and update of reserves and resources for fossil fuels:
  - i. Natural gas: Lower conventional reserves; Higher unconventional resources
  - ii. Oil: Conventional oil old and new data similar, but new unconventional resources lower compared to old data
  - iii. Hard coal: Higher resources in new data set
  - iv. Lignite: Lower resource numbers in new data set
- Global energy trade:
  - i. Trade in hard coal, pipeline gas, LNG, crude oil and the petroleum products distillates, gasoline, heavy fuel oil and naphtha expanded
  - ii. Transport costs:
    1. Variable cost approach for oil, coal and shipping of LNG
    2. Capacity approach for gas pipelines and liquefaction/regasification of LNG



## Summary (2)

- Base case with the new data set:
  - i. Primary energy supply increases from 407 PJ in 2005 to 1340 PJ in 2100
  - ii. Coal production nearly quintuples by the end of the century compared to today levels (for electricity and fuel production)
  - iii. With the new data set amounts of conventional oil and gas are nearly exhausted at the end of the century
  - iv. Oil:
    1. Regions with unconventional oil resources, Canada (oil sands) and USA (oil shale), become major oil suppliers in the second half of the century
    2. Worthwhile to have a closer look at alternative fuel production pathways (CTL, GTL, ethanol etc.)
  - v. Gas: Russia (CBM) and the Middle East (tight gas) will increase their share in global gas supply
  - vi. Without mitigation policies CO<sub>2</sub> emissions increase from 23 Gt in 2005 to 70 Gt in 2100
- New data provided in form of Excel files including scenario sheets to import data as scenario/trade scenario in VEDA-FE



## Review and update of fossil reserves and resources

- Review and update:
  - i. Regional reserves and resources for coal, gas and oil
  - ii. Regional supply costs for oil, coal and gas
- New data set summarized in Excel files with linked scenario sheet for import into VEDA-FE
  - i. Coal\_resources.xls
  - ii. Gas\_resources.xls
  - iii. Oil\_resources.xls

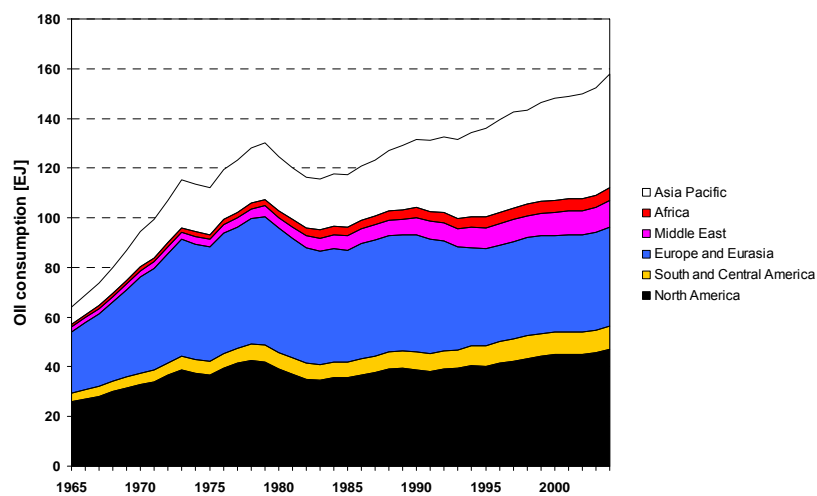


## Natural gas liquids

Region	2000			2005		
	NGL	Natural gas	NGL/Gas	NGL	Natural gas	NGL/Gas
	PJ	PJ	PJ <sub>NGL</sub> /PJ <sub>Gas</sub>	PJ	PJ	PJ <sub>NGL</sub> /PJ <sub>Gas</sub>
AFR	699	4773	0,146	917	5468	0,168
AUS	454	1377	0,329	655	1461	0,448
CAN	2748	6904	0,398	1563	6887	0,227
CHI	0	1026	0,000	0	1537	0,000
CSA	849	3684	0,231	780	4869	0,160
EEU	32	657	0,049	37	662	0,056
FSU	441	25406	0,017	516	27926	0,018
IND	294	1013	0,290	357	1110	0,322
JPN	0	0	-	0	0	-
MEA	3050	7787	0,392	4080	10547	0,387
MEX	817	1348	0,606	752	1398	0,538
ODA	427	6866	0,062	468	8068	0,058
SKO	0	0	-	0	0	-
USA	3953	20746	0,191	4164	20457	0,204
WEU	215	10099	0,021	537	11032	0,049
<b>World</b>	<b>13978</b>	<b>91687</b>	<b>0,152</b>	<b>14828</b>	<b>101421</b>	<b>0,146</b>

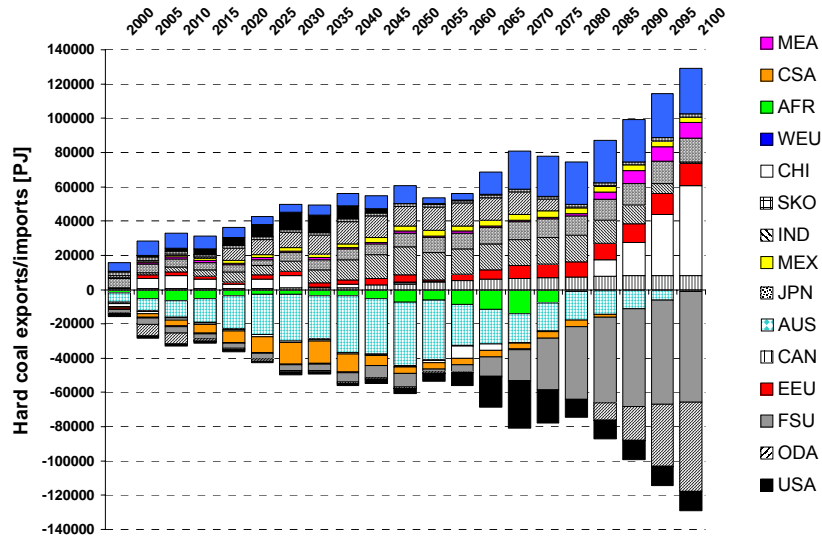


## Oil demand by world region





## Results: Hard coal trade



## Lignite

- Reserves and resources (based on the end of 1997):

EJ	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU	Total	
Reserves [EJ]	0	368	31	183	51	292	188	339	0	30	3	88	0	328	121	<b>2022</b>	
Resources [EJ]	2	427	29	839	198	542	1917	38	0	78	0	215	0	3826	809	<b>8922</b>	
Average heating value [MJ/kg]	8.79	9.67	-	11.72	11.72	8.79	7.33	8.79	-	8.79	-	8.79	-	8.79	14.65	5.57	<b>5.57</b>
	9.67	13.19	-	-	-	-	-	9.67	9.67	-	8.79	-	8.79	14.65	-	-	<b>17.0</b>

- Supply costs (reserves and resources modeled with only one cost step each):

\$/GJ	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Reserves	0.49	0.79	0.36	0.36	0.69	0.59	0.62	0.36	0.93	3.47	0.36	0.30	0.93	0.36	0.49
Resources	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70



## Coal trade

		Destination														
		AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Origin	AFR									44	42		0	73		1217
	AUS				37	146	0		388	2559	44	51	478	639	4	778
	CAN					95				391	24	27	39	168		148
	CHI			5						539		0		674	0	55
	CSA														82	657
	EEU					4					3					606
	FSU			1			26				155	2		76		287
	IND															
	JPN															
	MEA															
	MEX															
	ODA									433				161	19	254
	SKO															
	USA			520			2		1	101	65	12	3	46		572
WEU										2						

- Coal (steam+coking coal) trade in PJ for the year 2005
- Trade statistics for 2000 and 2005 as lower bounds
- Grey cells indicate trade links modeled in TIAM



## LNG contractual flows

