Review of the fossil resource base in the TIAM model
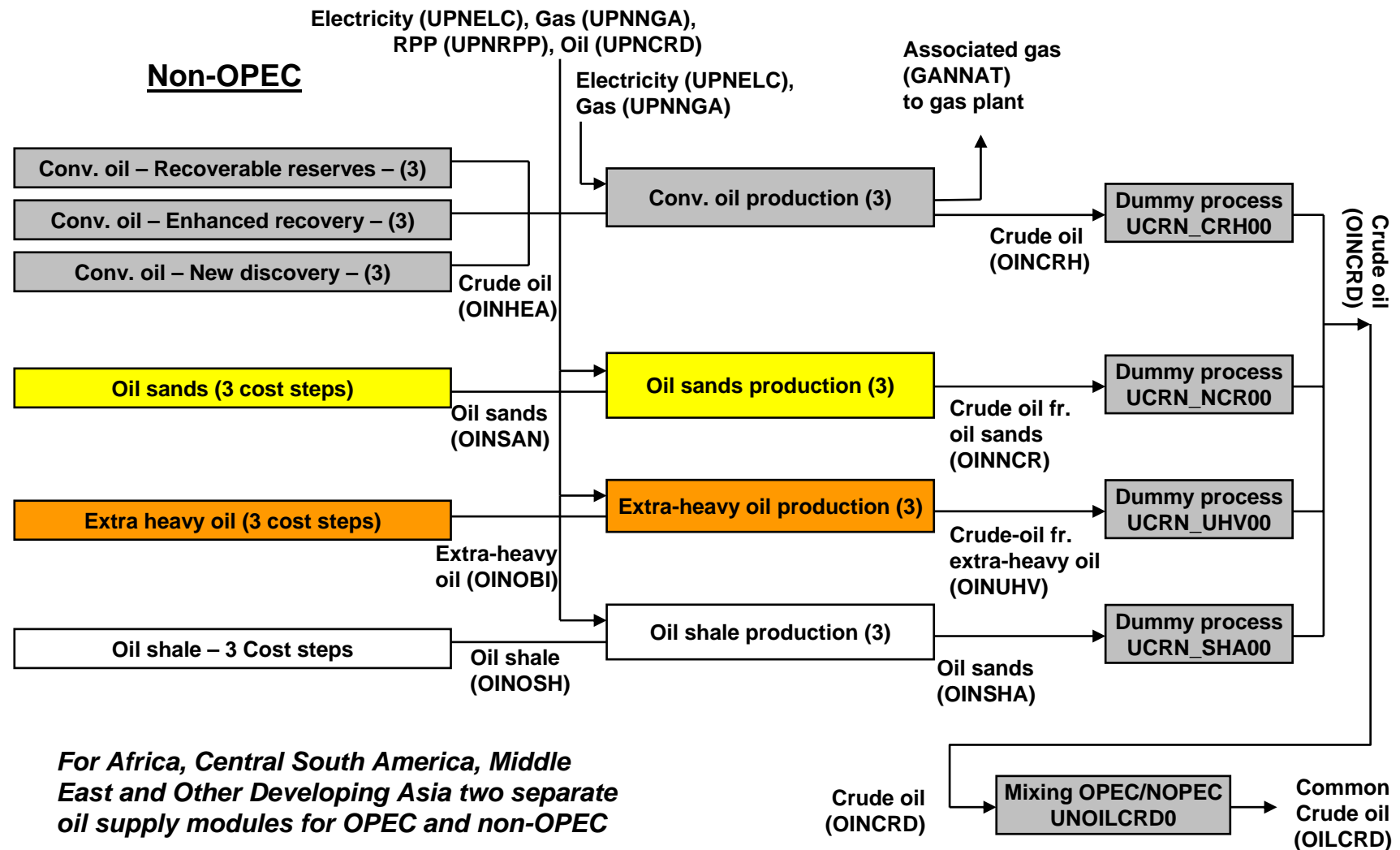
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Overview

- Modeling of the fossil reserves and resources in the TIAM model

- Review and update of the reserves and resource data for coal, gas and oil as well as their supply costs

- Review and update of the global trade structure for fossil fuels between world regions and introduction of transport costs

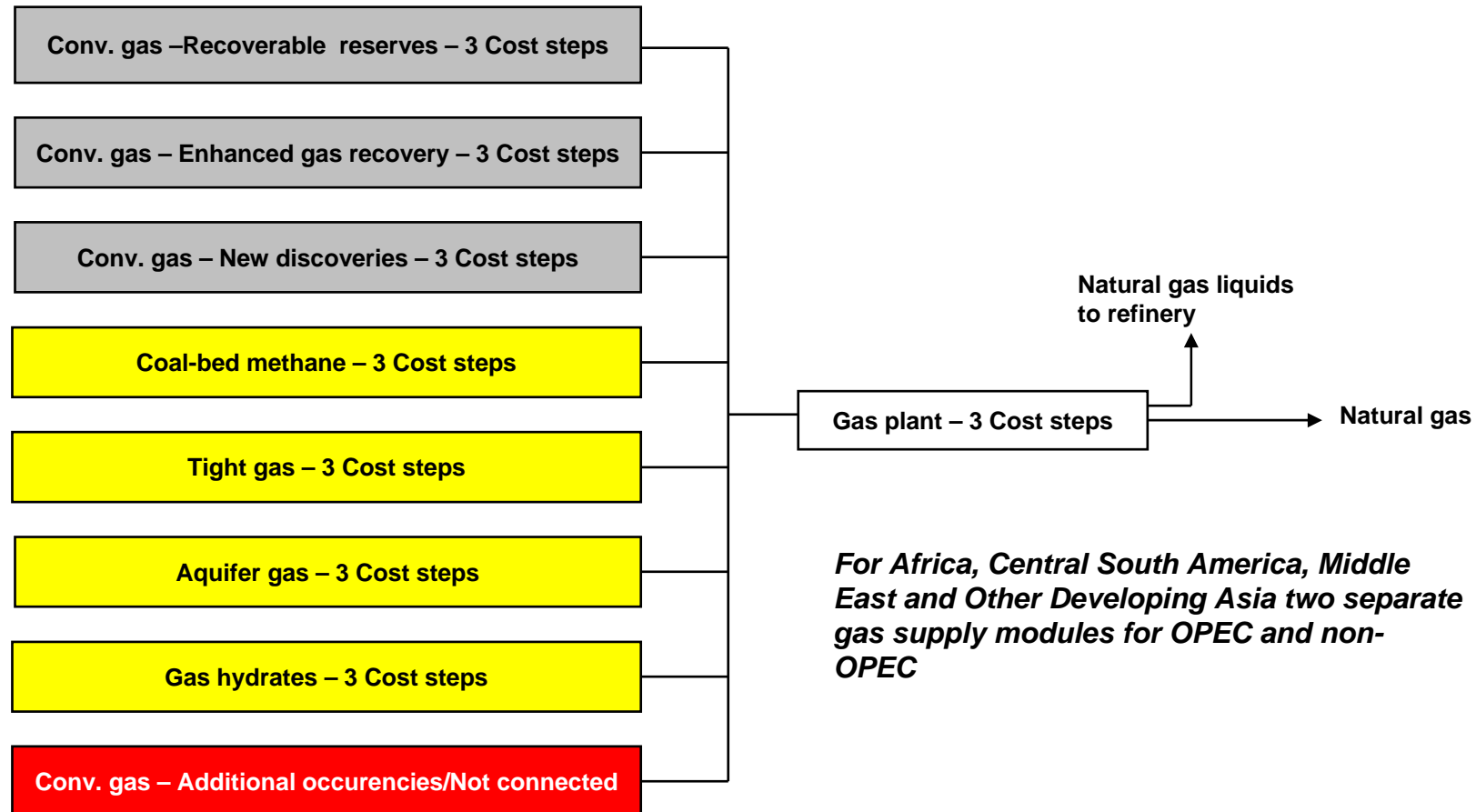- Comparision of example results with old and new data set

Modeling of oil supply in TIAM

Electricity (UPNELC), Gas (UPNNGA),
RPP (UPNRPP), Oil (UPNCRD)

Non-OPEC

Electricity (UPNELC),
Gas (UPNNGA)

Associated gas
(GANNAT)
to gas plant

| Conv. oil – Recoverable reserves – (3) |
| Conv. oil – Enhanced recovery – (3) |
| Conv. oil – New discovery – (3) |

Crude oil
(OINHEA)

Conv. oil production (3)

Crude oil
(OINCRH)

Dummy process
UCRN_CRH00

Crude oil
(OINCRD)

Oil sands (3 cost steps)

Oil sands
(OINSAN)

Oil sands production (3)

Crude oil fr.
oil sands
(OINNCR)

Dummy process
UCRN_NCR00

Extra heavy oil (3 cost steps)

Extra-heavy
oil (OINOBI)

Extra-heavy oil production (3)

Crude-oil fr.
extra-heavy oil
(OINUHV)

Dummy process
UCRN_UHV00

Oil shale – 3 Cost steps

Oil shale
(OINOSH)

Oil shale production (3)

Oil sands
(OINSHA)

Dummy process
UCRN_SHA00

*For Africa, Central South America, Middle
East and Other Developing Asia two separate
oil supply modules for OPEC and non-OPEC*

Crude oil
(OINCRD)

Mixing OPEC/NOPEC
UNOILCRD0

Common
Crude oil
(OILCRD)

Modeling of gas supply in TIAM

| Conv. gas –Recoverable reserves – 3 Cost steps |
| Conv. gas – Enhanced gas recovery – 3 Cost steps |
| Conv. gas – New discoveries – 3 Cost steps |
| Coal-bed methane – 3 Cost steps |
| Tight gas – 3 Cost steps |
| Aquifer gas – 3 Cost steps |
| Gas hydrates – 3 Cost steps |
| Conv. gas – Additional occurencies/Not connected |

Natural gas liquids to refinery

Gas plant – 3 Cost steps → **Natural gas**

For Africa, Central South America, Middle East and Other Developing Asia two separate gas supply modules for OPEC and non-OPEC

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

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

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	**2022**
Resources [EJ]	2	427	29	839	198	542	1917	38	0	78	0	215	0	3826	809	**8922**
Average heating value [MJ/kg]	8.79 - 9.67	9.67 - 13.19	11.72	11.72	8.79 - 9.67	7.33 - 14.65	8.79 - 13.19	9.67	9.67	8.79 - 9.67	8.79	8.79 - 9.67	8.79	14.65	5.57 - 17.0	**5.57 - 17.0**

- 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

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
Reserves [EJ]	1243	1605	90	2523	370	298	4597	2196	9	35	22	170	2	6135	46	**19342**
Resources [EJ]	2989	3650	1193	21275	847	1317	45410	114	3872	119	48	5197	0	9864	306	**96201**
Average heating value [MJ/kg]	22.86 - 24.91	23.45 - 26.38	27.84	21.1	20.52 - 27.55	17.58 - 24.91	19.34 - 23.45	20.8	22.8	23.45 - 26.67	23.5	19.05 - 23.45	23.5	25.2	20.52 - 27.55	**19.05 - 27.55**

● 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	**1.03**	**1.06**	**1.87**	**1.36**	**0.96**	**1.53**	**0.86**	**1.60**	**3.65**	**4.00**	**1.87**	**1.18**	**3.65**	**1.31**	**3.65**
Resources	**1.37**	**1.40**	**2.20**	**1.70**	**1.30**	**1.87**	**1.20**	**1.94**	**4.01**	**4.34**	**2.20**	**1.53**	**4.01**	**1.66**	**4.01**

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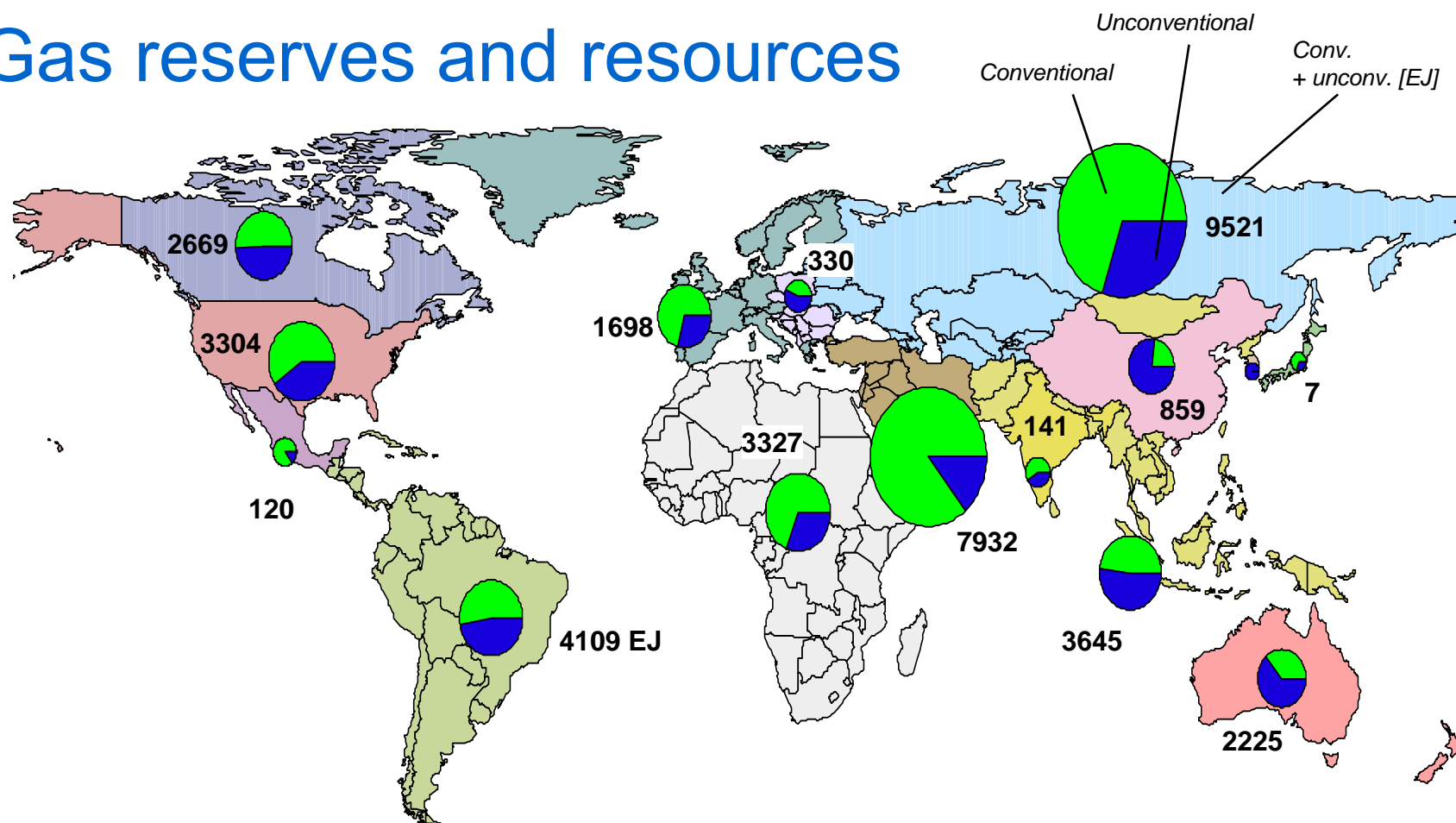
Conventional [EJ]		Unconventional reserves + resources [EJ]			Total [EJ]	Gas hydrates resources [EJ]	Gas production 2004 [EJ]
Reserves	Resources	Coal-bed methane	Tight gas	Aquifer gas			
12673	5256	2827	1694	17441	39890	47400	88

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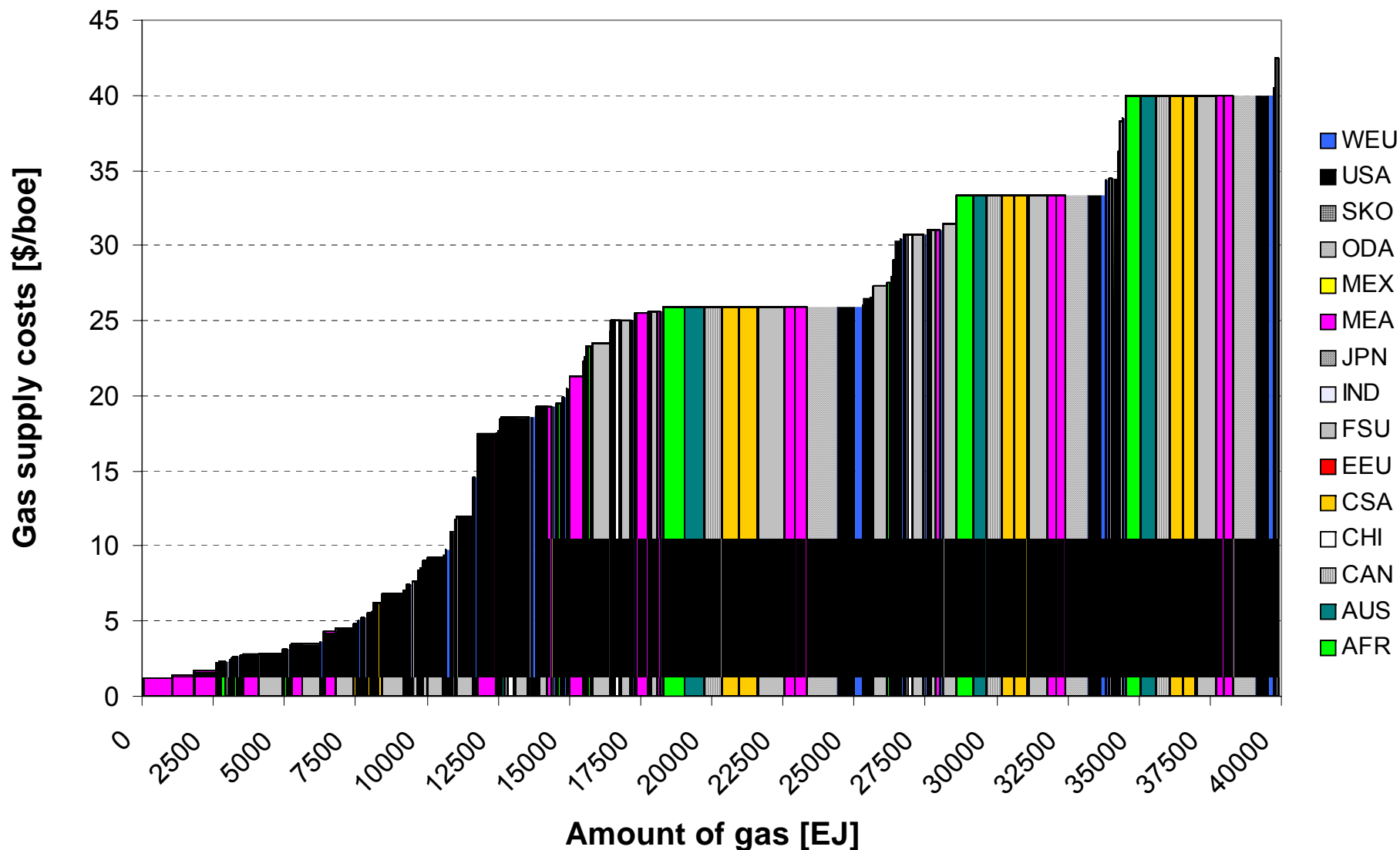
Oil reserves and resources
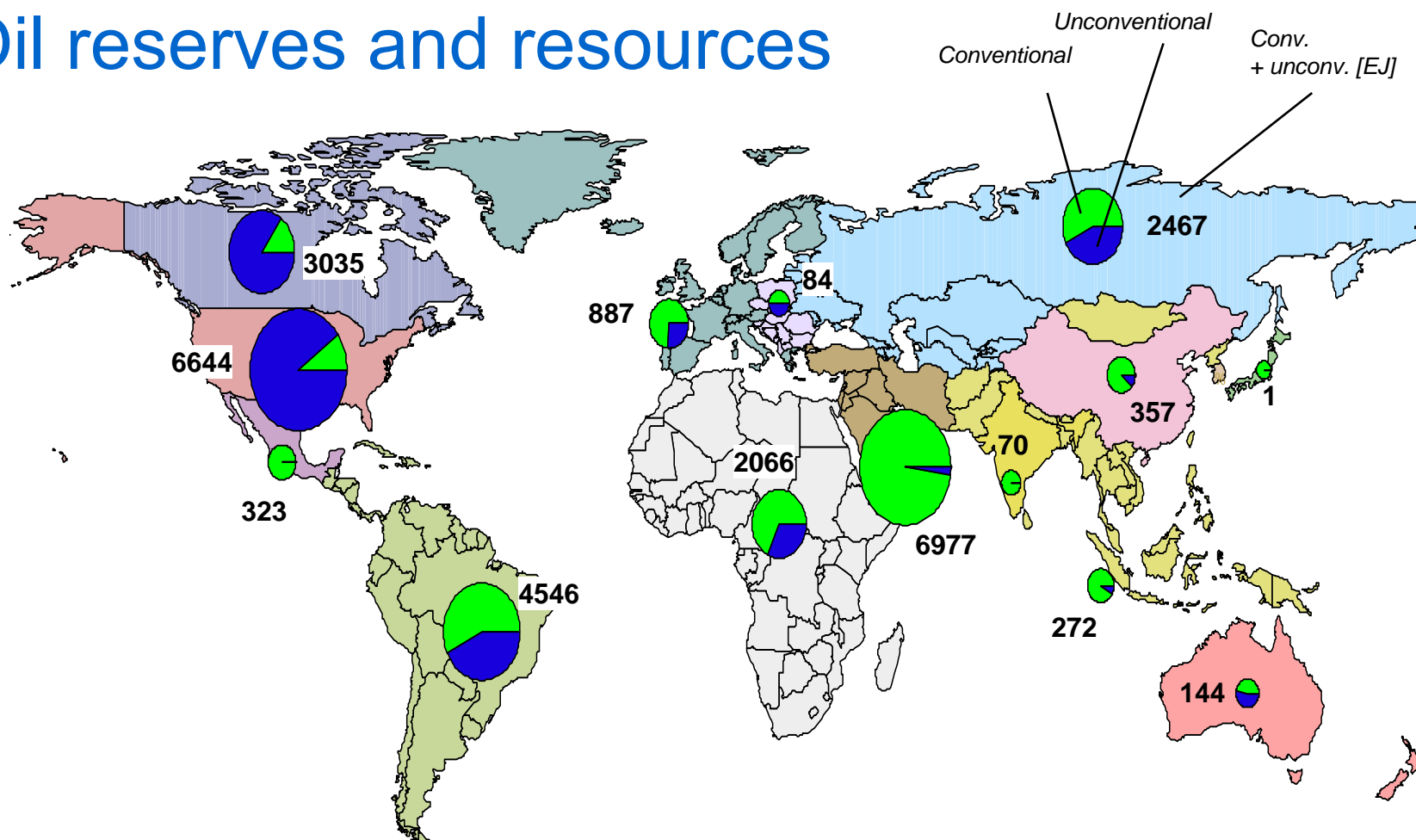
Conventional [EJ]		Unconventional reserves + resources [EJ]			Total [EJ]	Production 2004 [EJ]
Reserves	Resources	Tar sand	Extra heavy oil	Shale oil		
11 776	3 618	3 117	1 616	7 745	27 873	161

Global oil supply cost curve
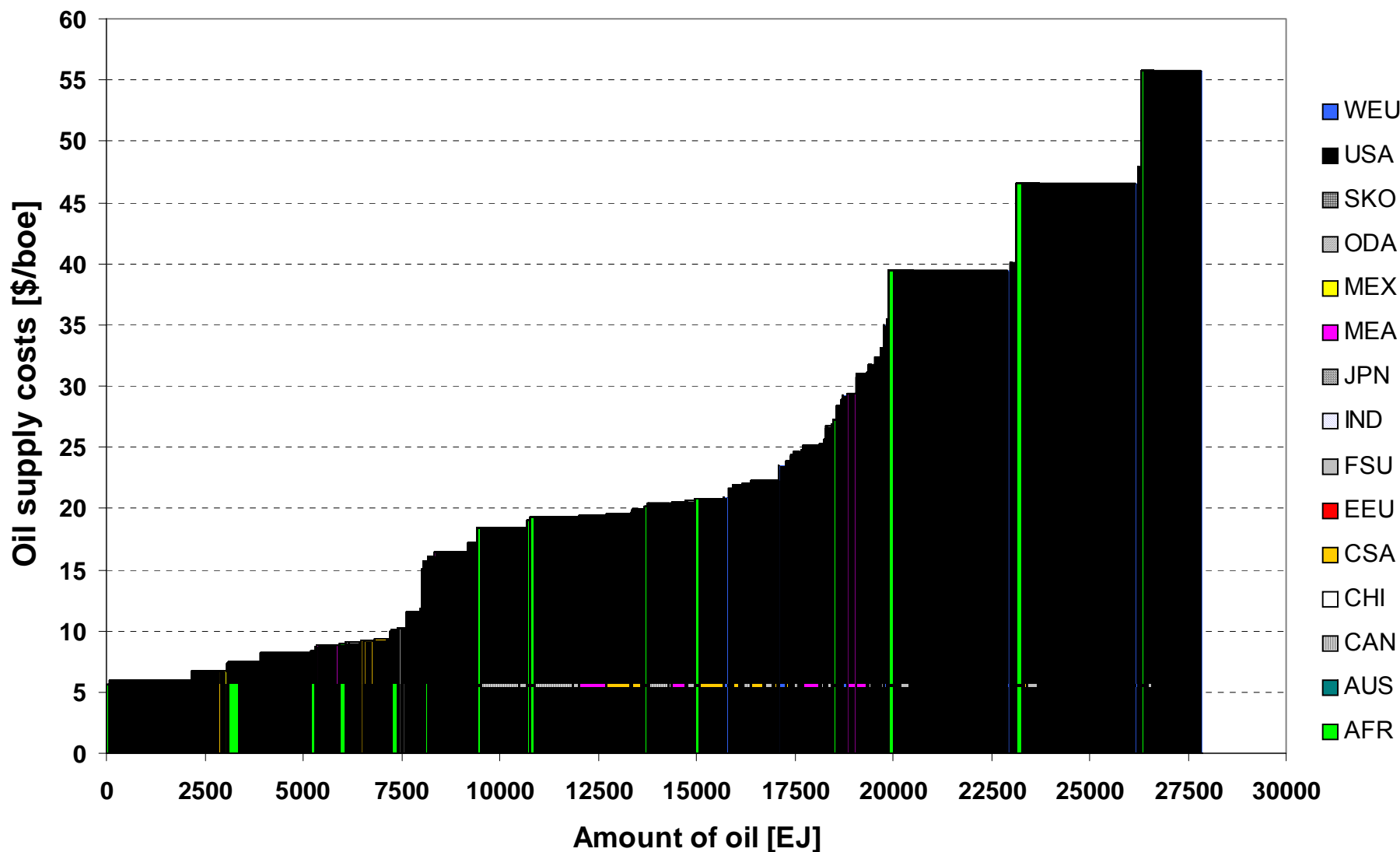
Comparison of old and new reserve and resource data

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
Total	**17,928**	**28,998**	**21,962**	**3,515**	**15,394**	**15,202**	**12,479**	**27,113**	**115,541**	**87,745**	**10,944**	**80,456**

- 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

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

Coal trade

Origin \ Destination	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
AFR	■		2						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

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

Existing natural gas pipelines between world regions

Origin		Destination		Capacity	Major Pipelines
Region	Country	Region	Country	PJ/a	
FSU	Russia	**WEU**	Finland	401	Finland Connector
	Belarus	EEU	Poland	1242	Yamal Pipeline
	Ukraine	EEU	Poland	361	
FSU	Ukraine	EEU	Slovakia	4327	Brotherhood pipeline
	Ukraine	EEU	Hungary	601	
	Ukraine	EEU	Romania	1322	Shebelynka-Izmail Pipeline
FSU		**EEU**	Total	7853	
	Poland	WEU	Germany	1082	Yamal Pipeline
EEU	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	
	Algeria	WEU	Spain	441	Maghreb-Europe Gas Pipeline (MEG)
AFR	Algeria	WEU	Italy	1162	Transmeditteranean 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	

LNG gas trade

Origin \ Destination	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
AFR									3	196			12	202	1412
AUS								6	523			16	46		3
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

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
Total	**455.8**	**Total**	**247.7**

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

Crude oil trade

Origin \ Destination	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
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	11139
IND															
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

Specific transport costs
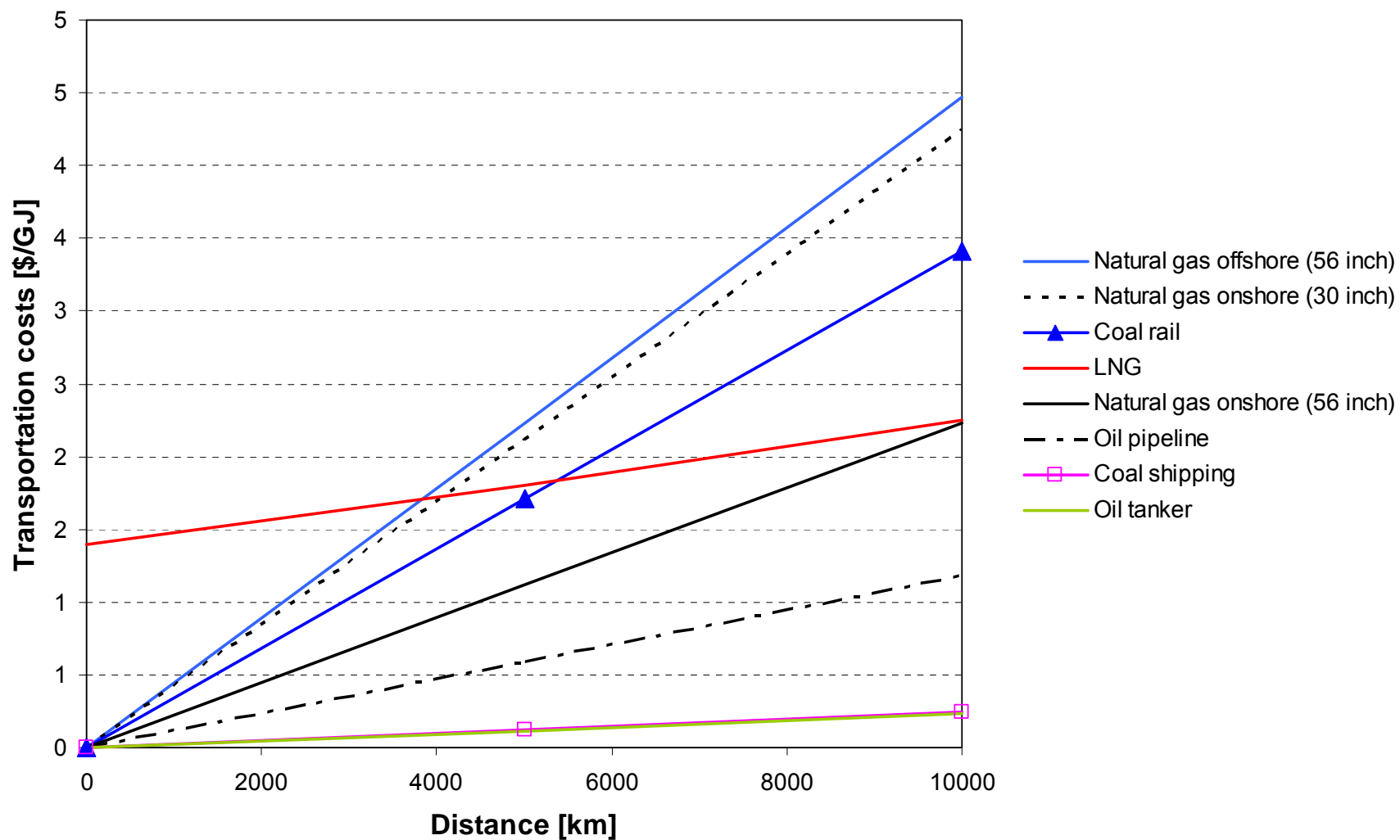
Example: Calculation of LNG shipping costs (1)

		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_{maint})	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^3 LNG
Loading factor (lf)	0.98	
Total transport capacity in one year (cap_{tot})	1193860	m^3 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 annual costs ($cost_{spec}$)	21.31	$/$m^3$ LNG

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

- Formulas for calculating specific transport costs:

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

Number of trips per year

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

Total transport capacity In one year

$$cost_{spec} = \frac{annuity + fom/100 \cdot inv}{cap_{tot}}$$

Specific annual transport costs

Comparison of model results

- Comparison of TIAM results between old and new data set

- Calculation for base scenario
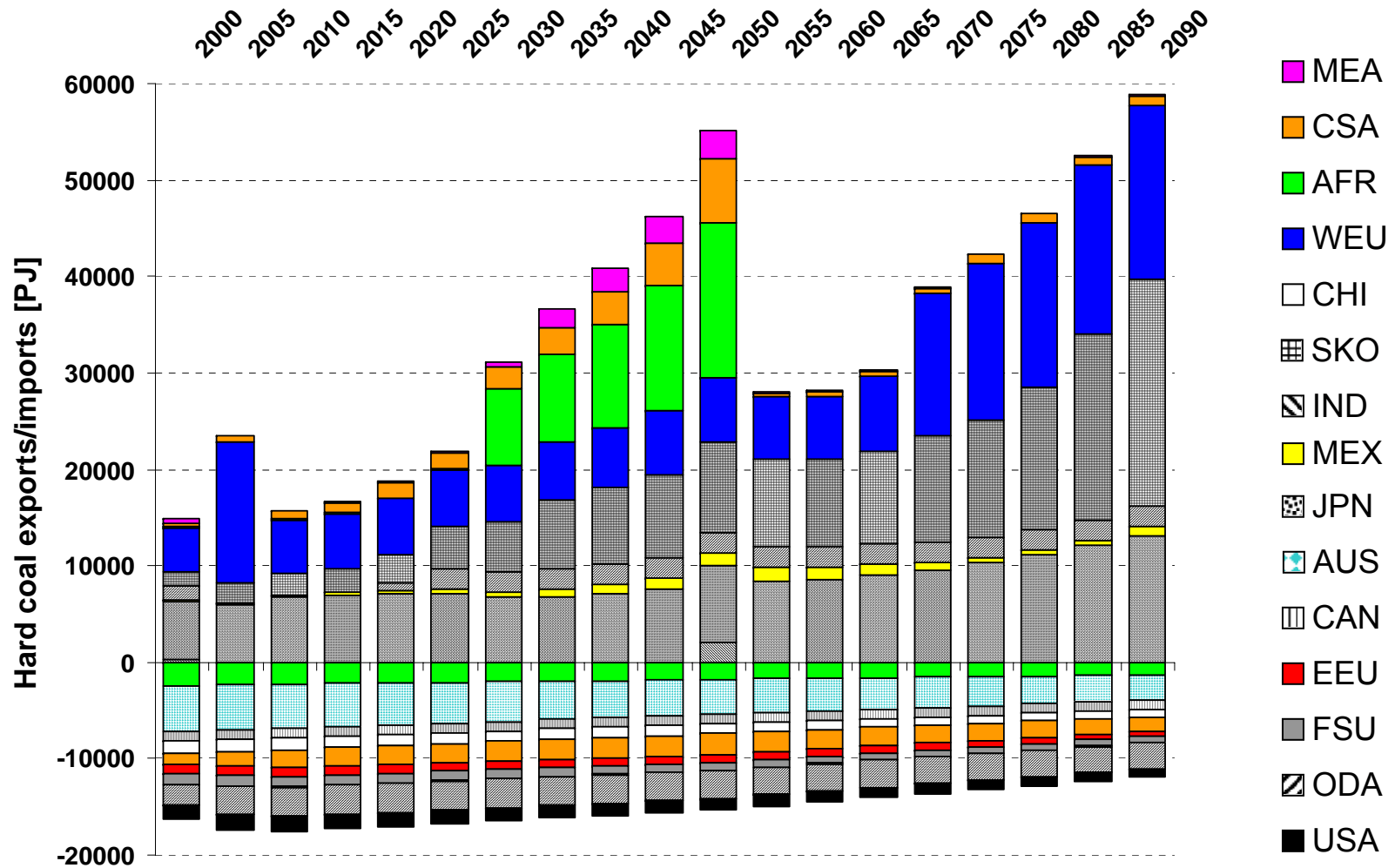
Results: Primary energy supply
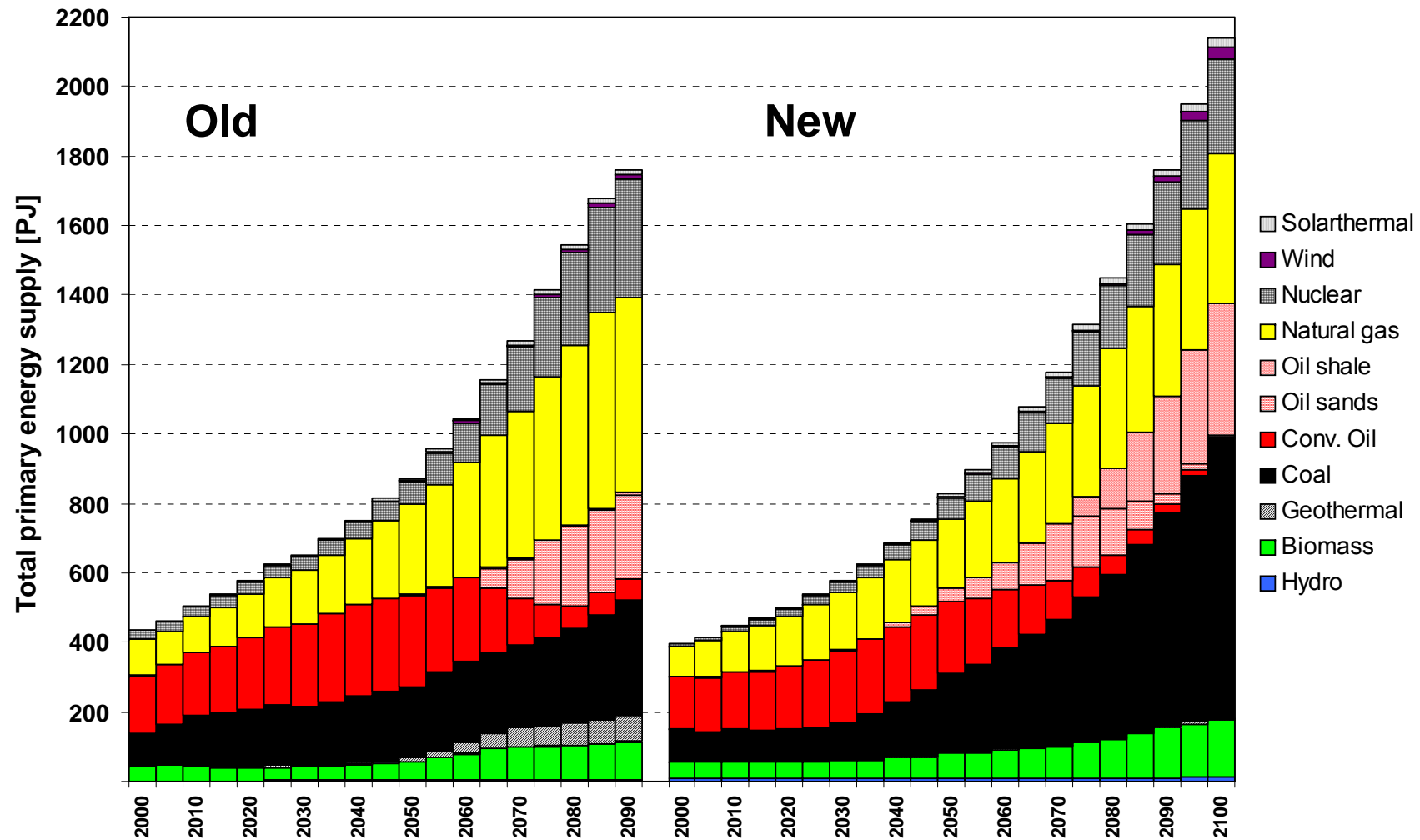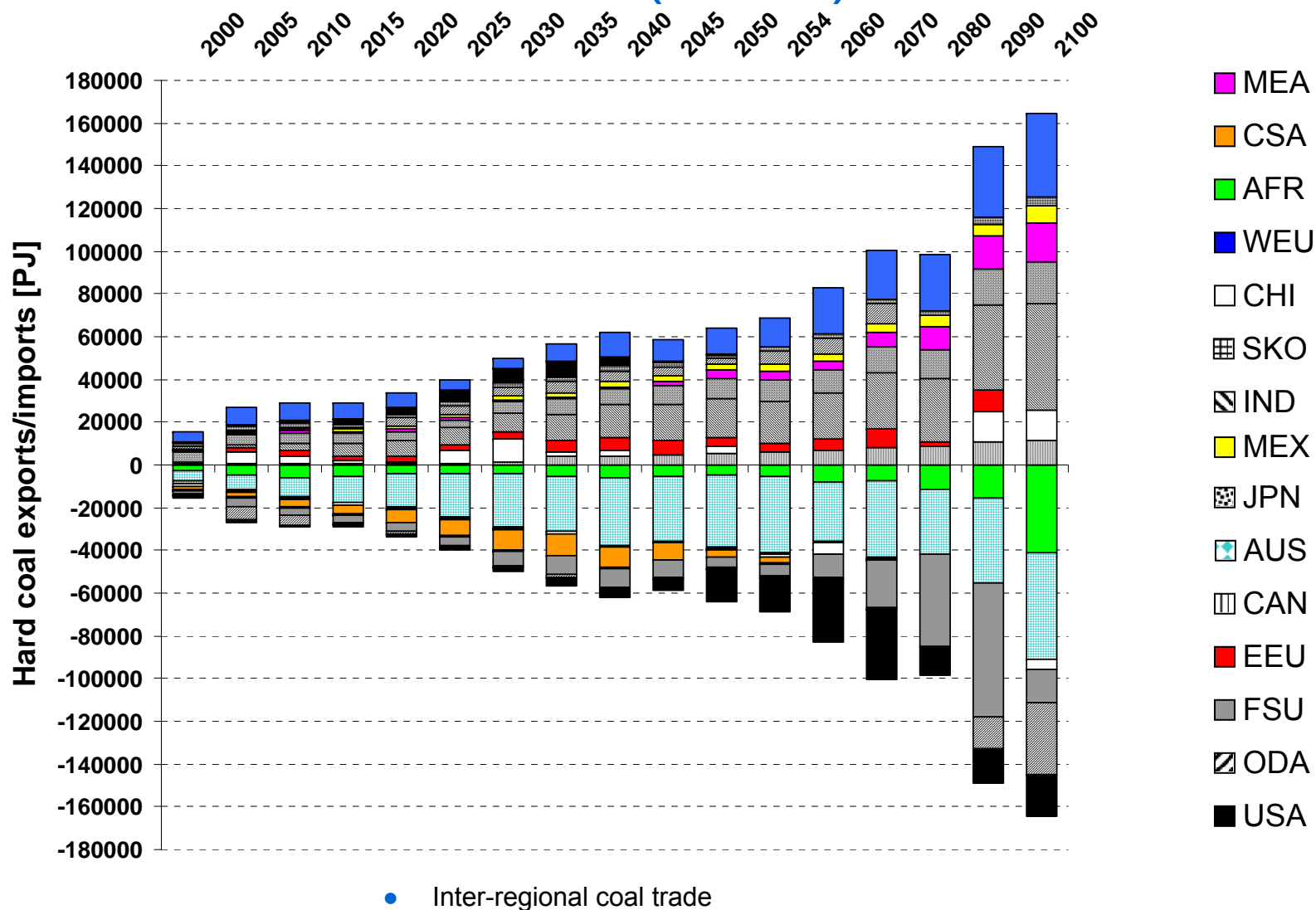
Results: Crude oil production
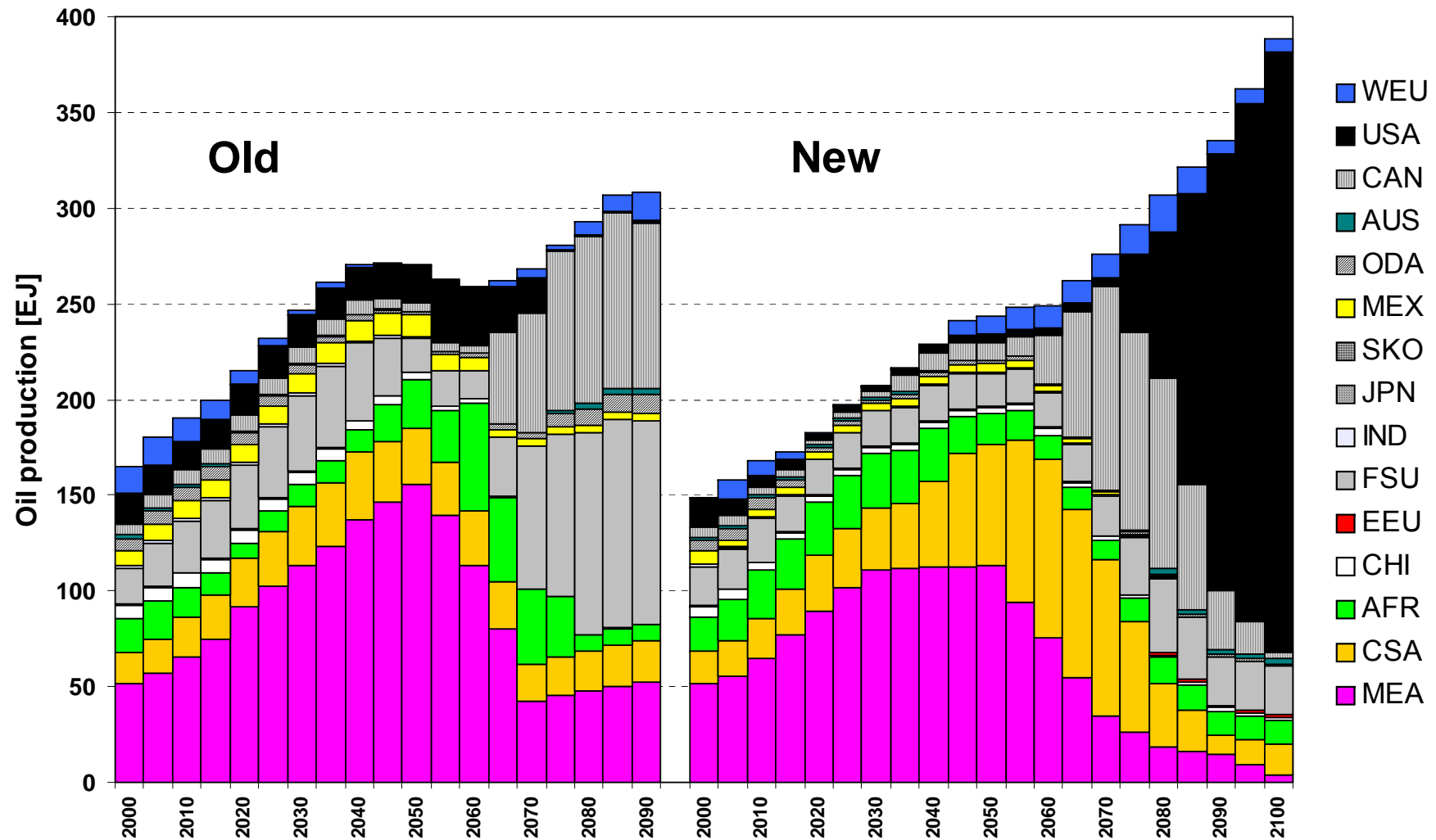
Results: Hard coal trade (OLD)

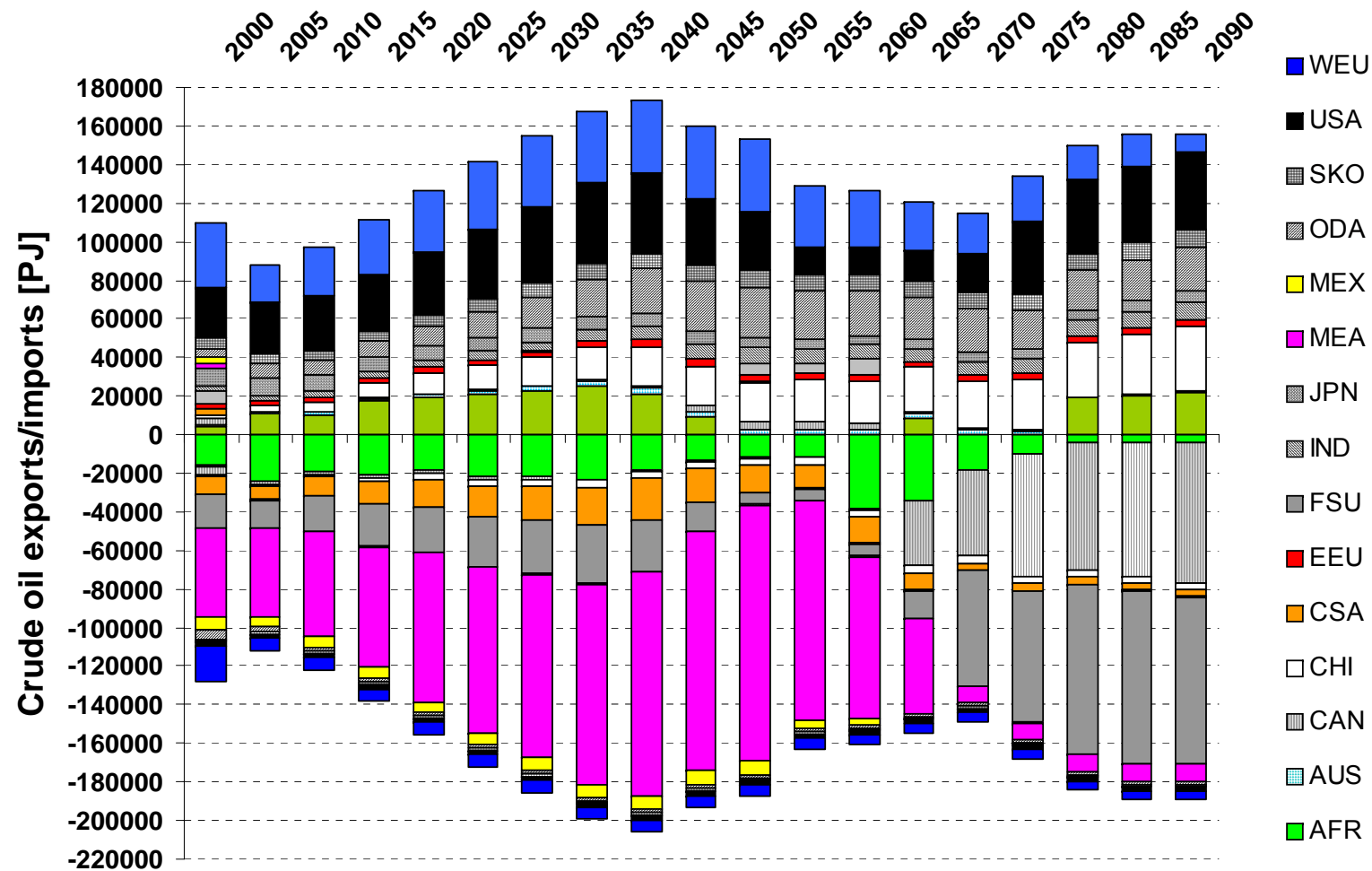- Due to exogenous imports and exports of coal do not balance, no inter-regional coal trade
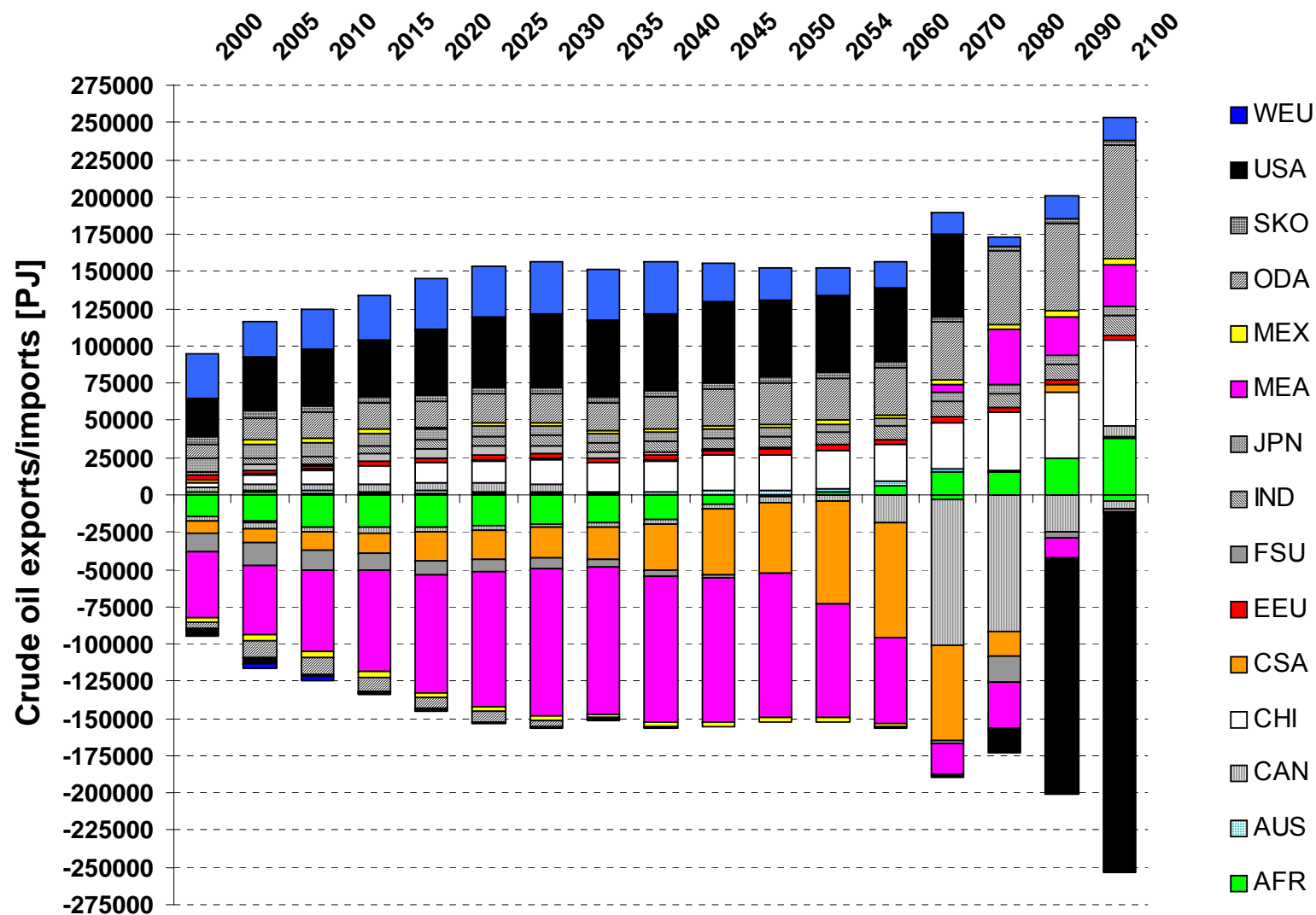
Results: Hard coal trade (NEW)

Inter-regional coal trade

Results: Crude oil trade (OLD)

● Due to exogenous exports to a generic region outside of the world regions imports and exports are not balanced

Results: Crude oil trade (NEW)

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

- Model runs with the new data set:
  i. Inter-regional imports and exports are balanced
  ii. Dummy imports are nearly eliminated with the exception of the base year due to

Summary (2)

- Model runs with the new data set:

  i. Inter-regional imports and exports are balanced

  ii. Dummy imports are nearly eliminated with the exception of the first period due to some calibration bounds

  iii. With the new data set amounts of conventional and unconventional oil as well as conventional gas nearly exhausted (-> worthwhile to have a closer look at alternative fuel production options)

- New data provided in form of Excel files including scenario sheets to import data as scenario/trade scenario in VEDA-FE