POST-PARIS CLEAN ENERGY OPTIONS: THE CASE OF CHINA

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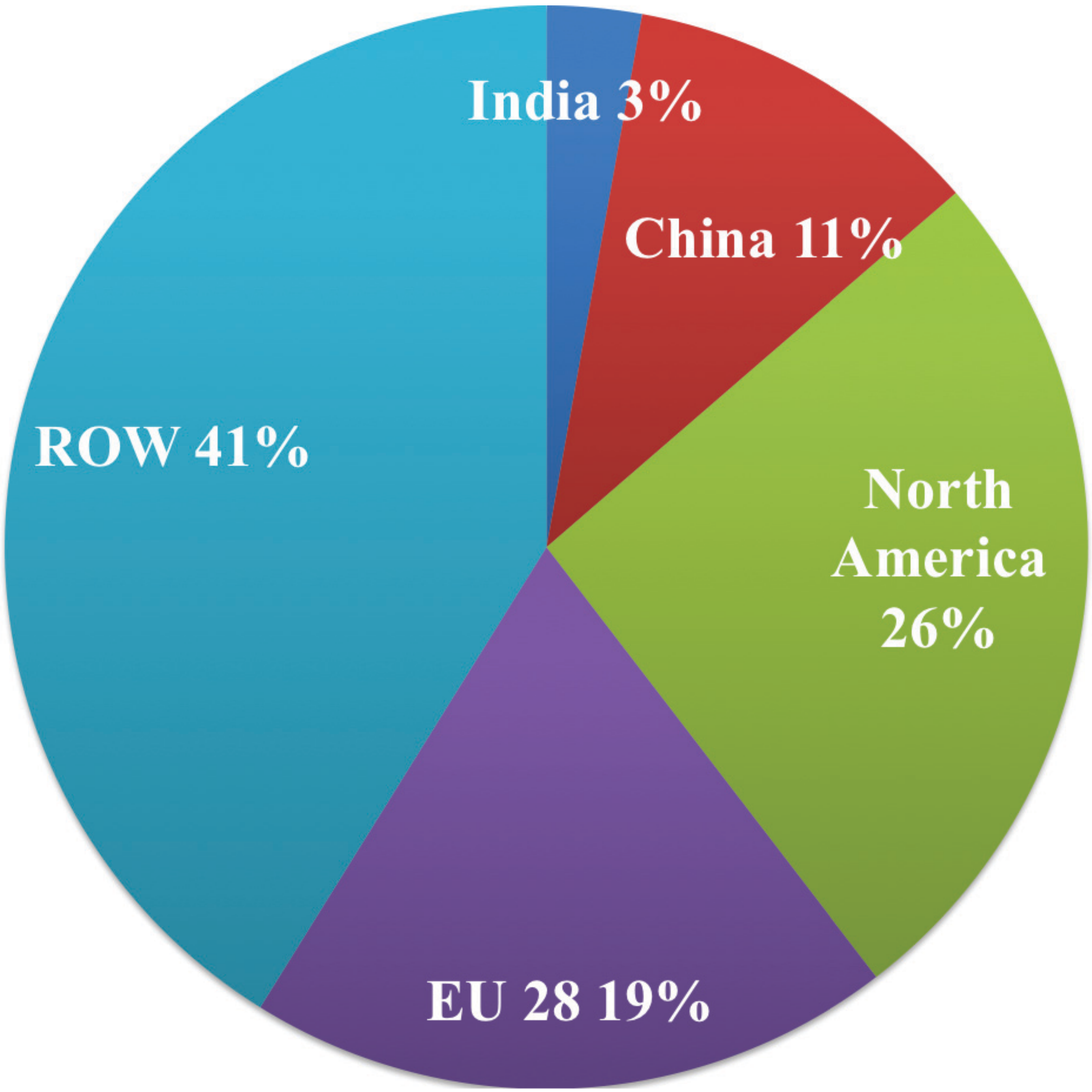
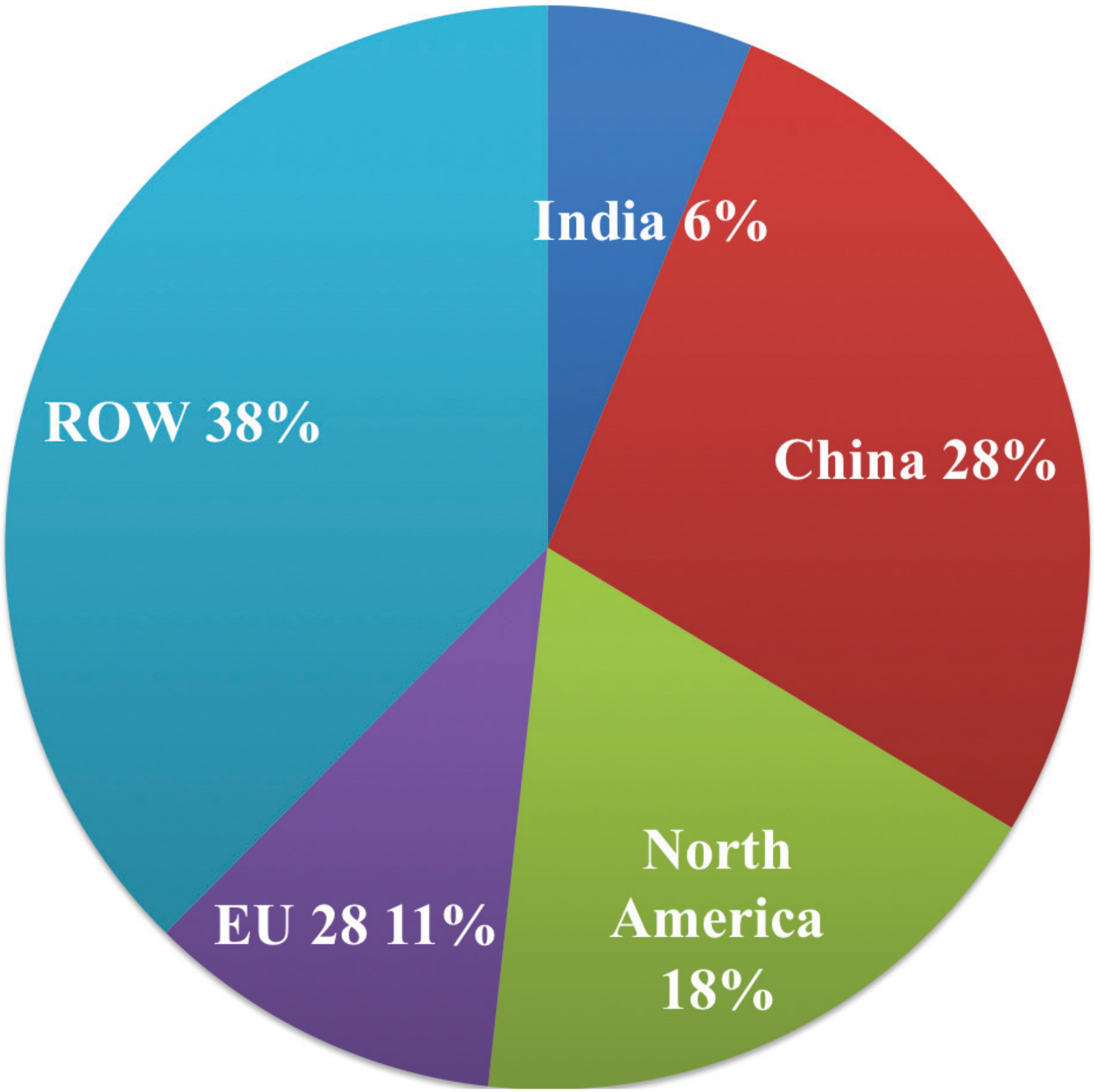
Top Carbon Emitters in 1990



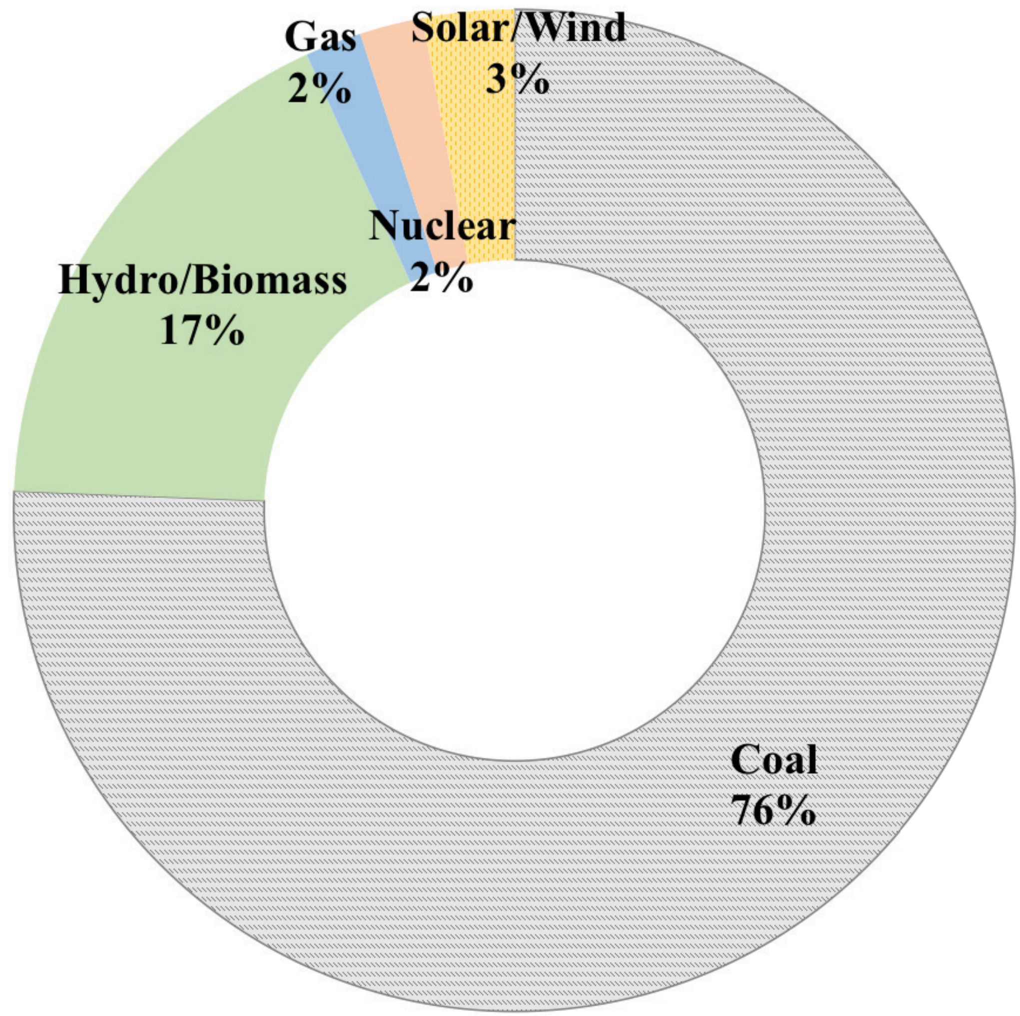
Top Carbon Emitters in 2012



Chinese Commitments for 2030

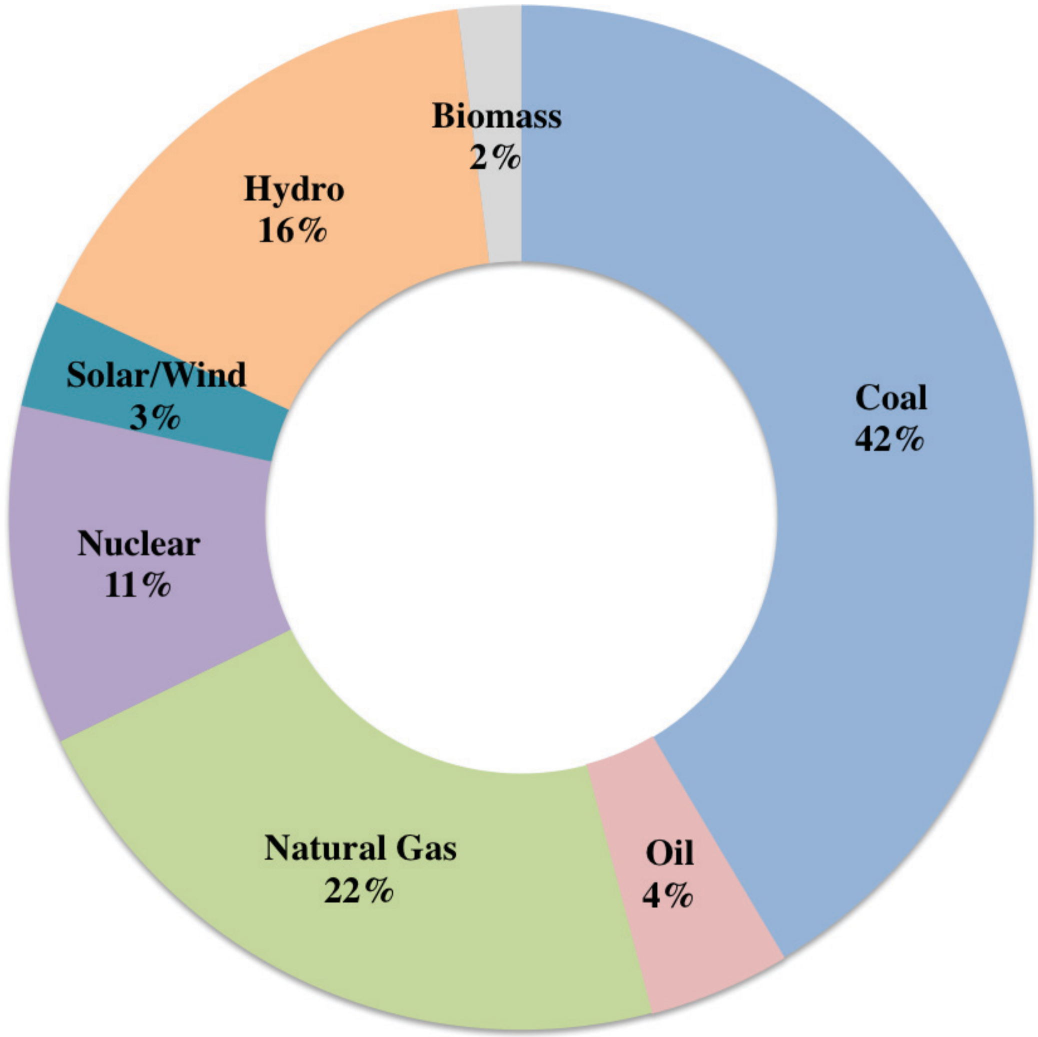
- PEAK EMISSIONS BY 2030
- LOWER CARBON INTENSITY BY 60-65% FROM 2005
- INCREASE SHARE OF NON-FOSSIL FUELS TO 20%
- INCREASE STOCK OF FORESTS BY 4.5 BILLION CUBIC METERS

Chinese Electricity Output by Fuel



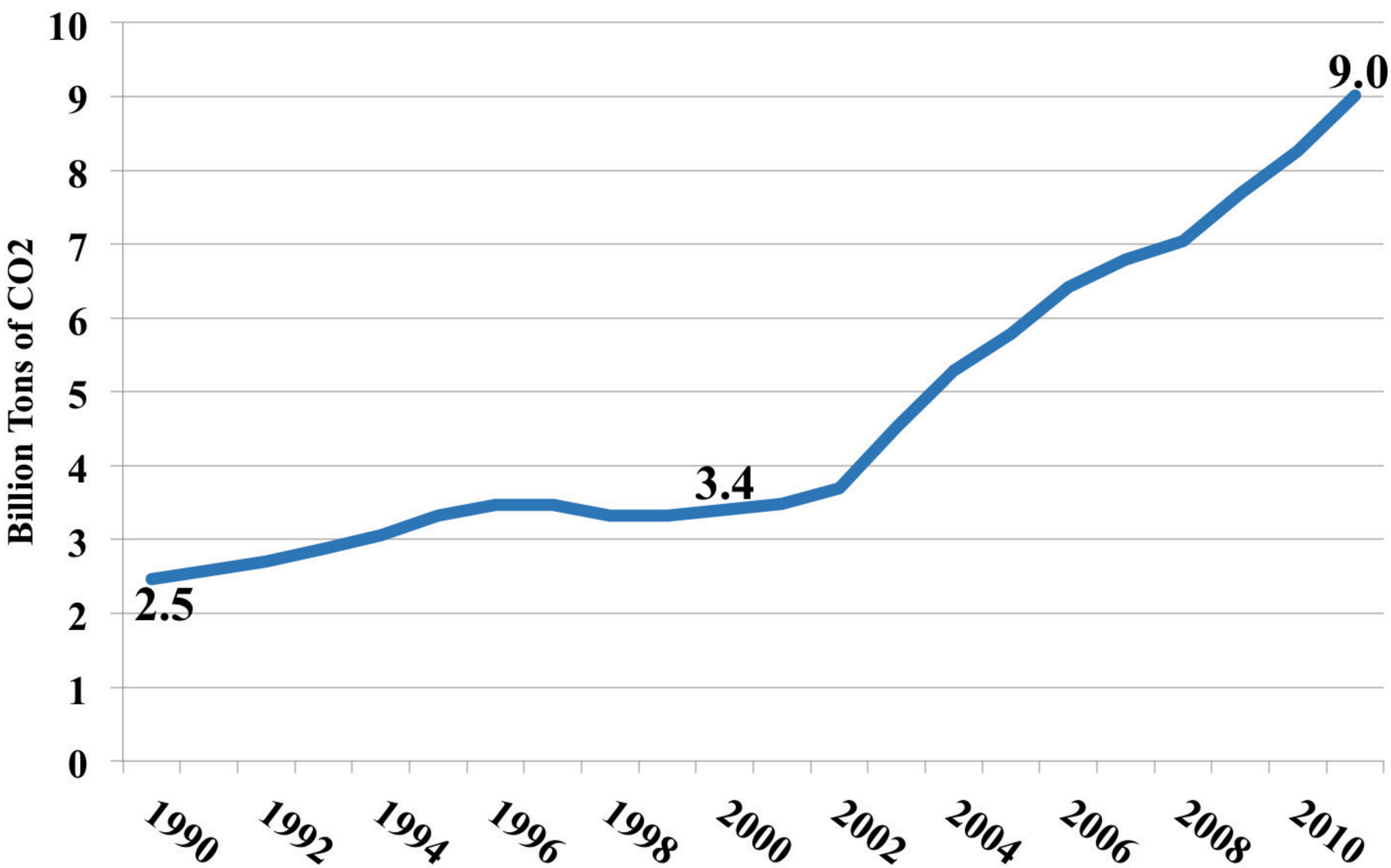
Total Production: **4.7 PWh** (IEA)

World Electricity Output by Fuel



Total Production: **22.7 PWh** (IEA)

Time Path of Chinese CO2 Emissions

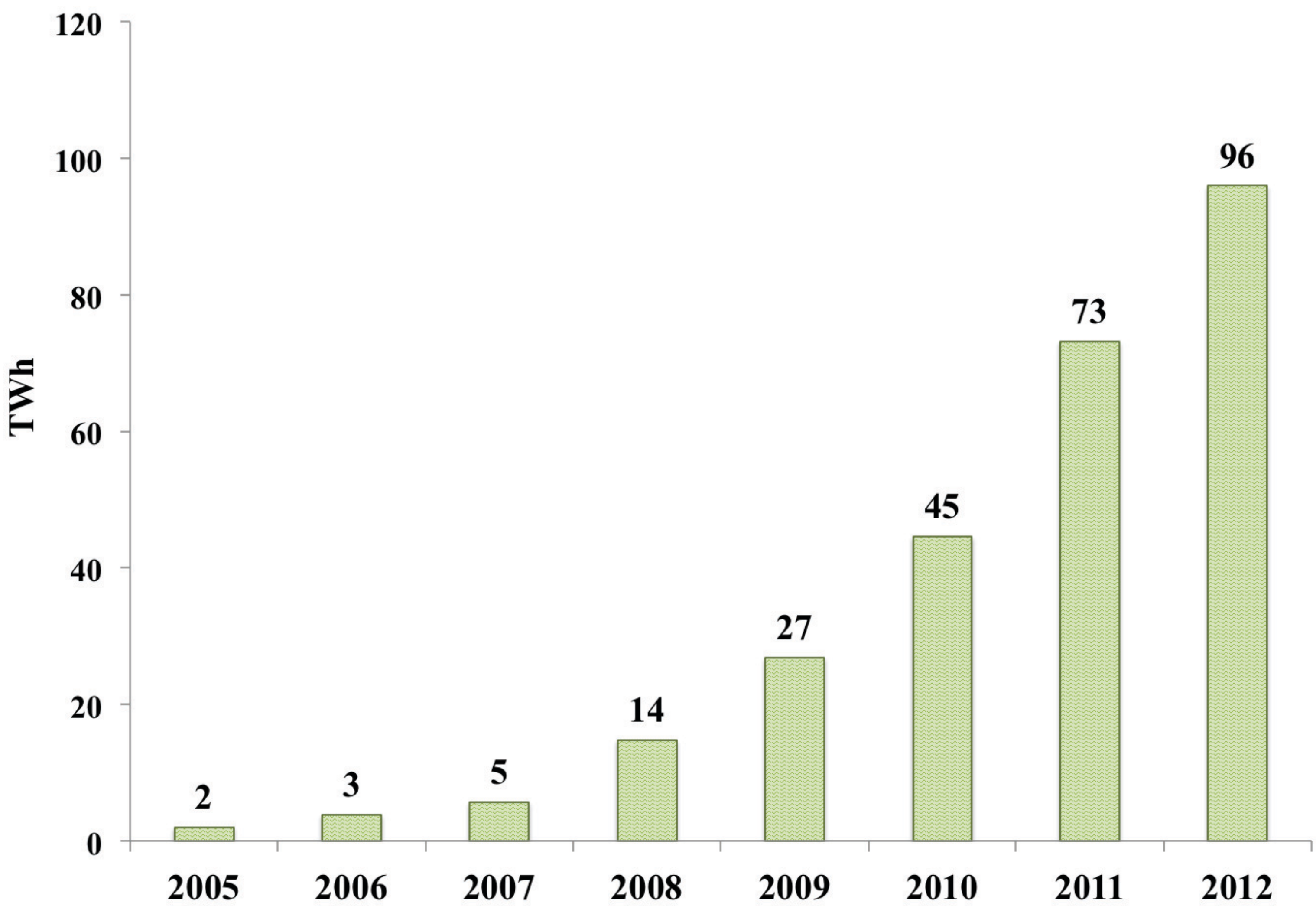


Source: World Bank 2016

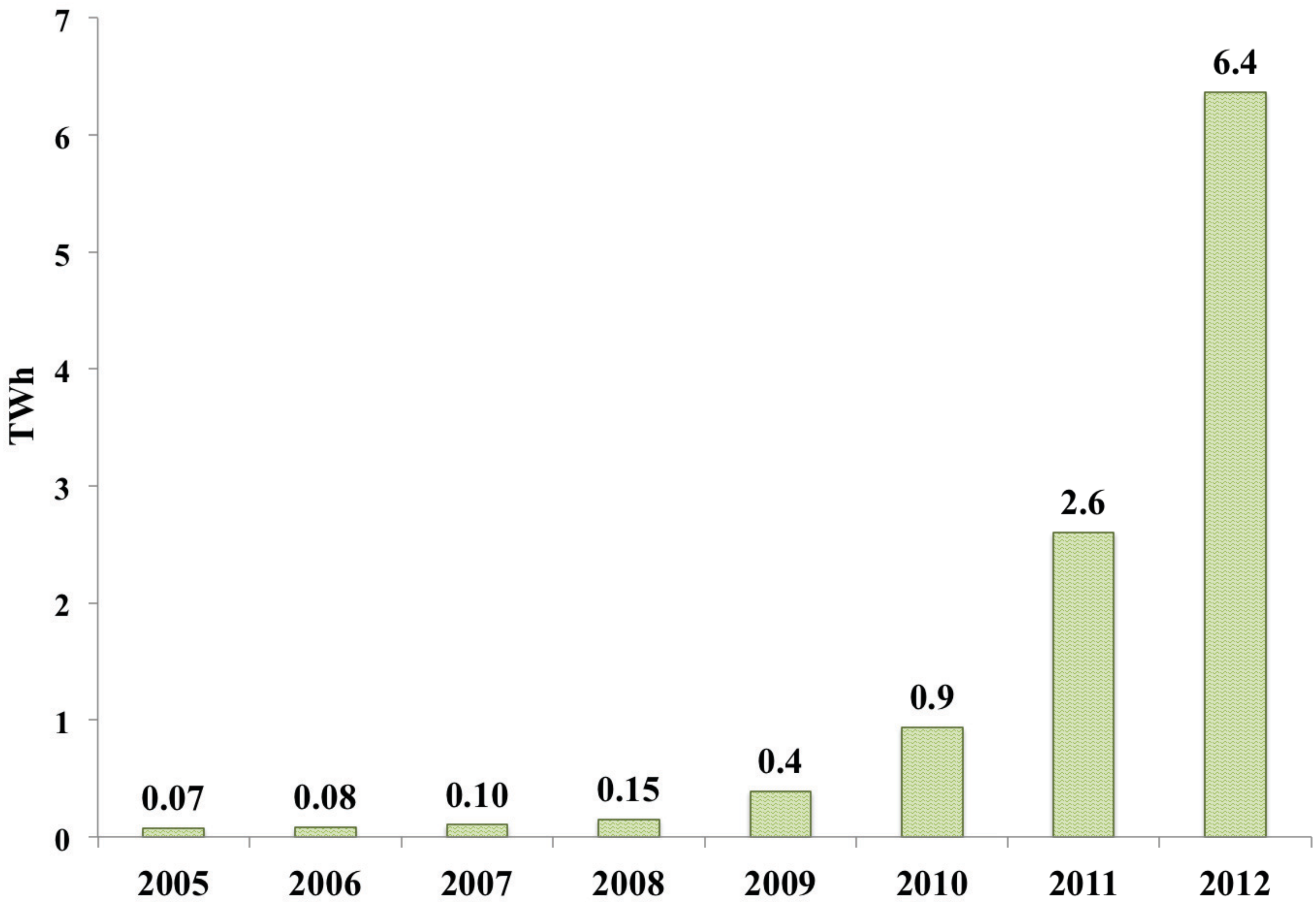
Installed Capacity of Chinese Wind and Solar

- Solar PV 40 GW (US = 18)
- Wind 145 GW (US = 74)

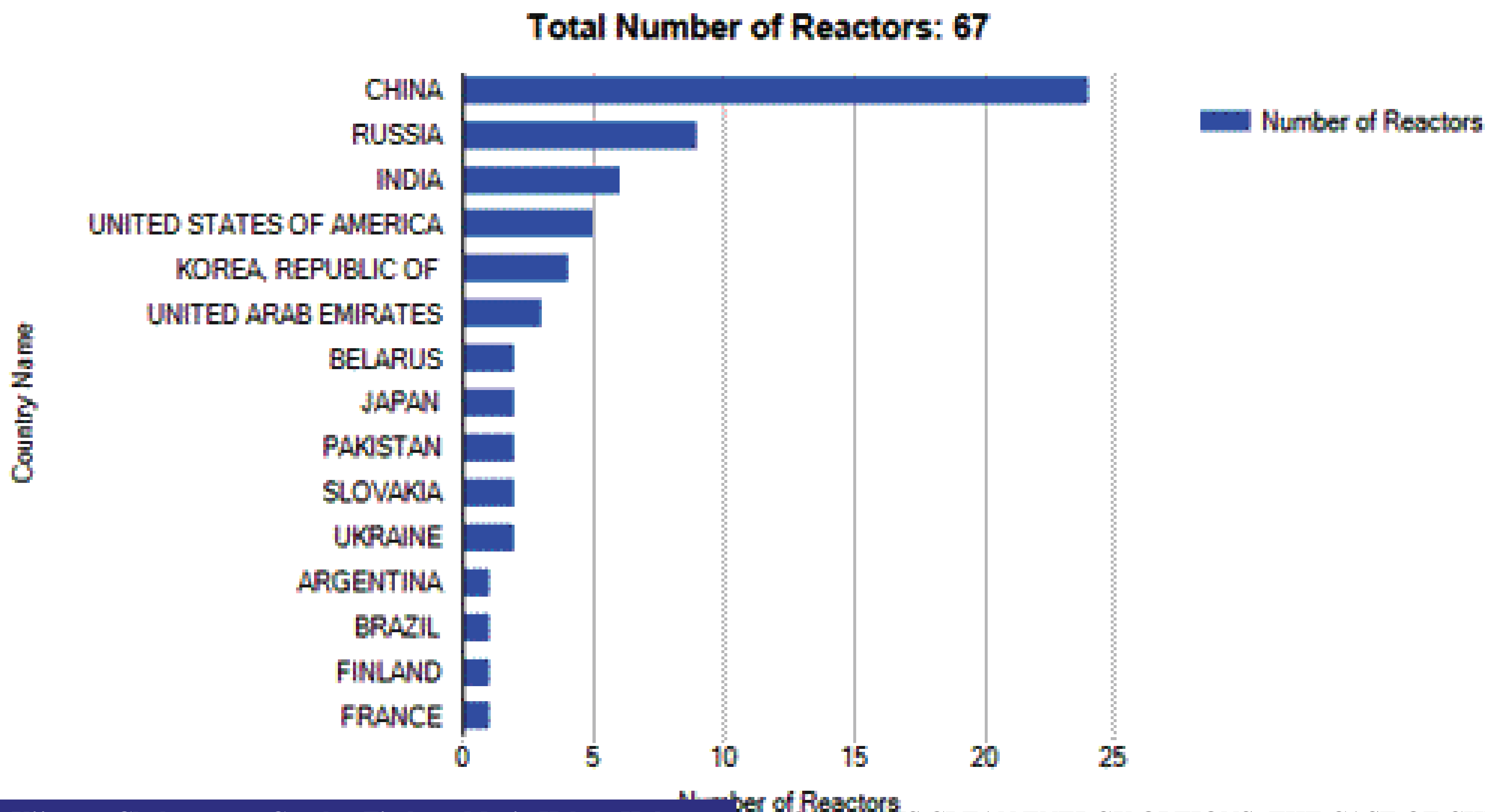
Growth of Wind Power in China



Growth of Solar Power in China



Nuclear Power in China: Number of Reactors Under Construction, 2015



Nuclear Capacity by Country, 2015

Country	In operation		Under construction	
	Number	Electr. net output MW	Number	Electr. net output MW
Argentina	3	1,627	1	25
Armenia	1	375	-	-
Belarus	-	-	2	2.218
Belgium	7	5,921	-	-
Brazil	2	1,884	1	1,245
Bulgaria	2	1,926	-	-
Canada	19	13,500	-	-
China	27	23,025	24	23,738
Czech Republic	6	3,904	-	-
Finland	4	2,752	1	1,600
France	58	63,130	1	1,630
Germany	9	12,074	-	-
Hungary	4	1,889	-	-
India	21	5,308	6	3,907
Iran	1	915	-	-
Japan	43	40,290	2	2.650
Korea, Republic	24	21,667	4	5,420
Mexico	2	1,330	-	-
Netherlands	1	482	-	-
Pakistan	3	690	2	630
Romania	2	1,300	-	-
Russian Federation	34	24,654	9	7,371
Slovakian Republic	4	1,814	2	880
Slovenia	1	688	-	-
South Africa	2	1,860	-	-
Spain	7	7,121	-	-
Sweden	10	9,651	-	-
Switzerland	5	3,333	-	-
Taiwan, China	6	5,032	2	2,600
Ukraine	15	13,107	2	1,900
United Arab Emirates	-	-	3	4,035
United Kingdom	16	9,373	-	-
USA	99	98,639	5	5,633
Total	**438**	**379,261**	**67**	**65,482**

and under construction, IAEA as of 1 June 2015

Nuclear Power 101

- Current Installed Capacity = 380 GWe
- Total Power Generated from Nuclear in 2014 = 2410 TWh
- Output per GWe of Capacity = 6.34 TWh (Max: 8.76 TWh)
- IEA Projections = 767 GWe by 2040
- Average Annual Growth of Nuclear Capacity = 14.9 GWe

Can Nuclear Power Meet Chinese Paris Commitments?

- Annual growth of power supply from nuclear at 95.3 TWh
- Allocated according to share of plant construction by region
- China: 50%, ROW: 35%, North America: 15%
- Annual Growth in Nuclear Power of 47.6 TWh
- 2014 nuclear output: 124 TWh (or 2% of electricity generated)
- IAEA Projections for Nuclear: 1,065 TWh in 2030 (or 20% of electricity generated)

A Simple Three Agent Model to Study Chinese Clean Energy Policy

- We build a dynamic, partial equilibrium model
- The model has 3 regions and no strategic behavior
    - China
    - North America (US, Canada and Mexico)
    - Rest Of the World (ROW)

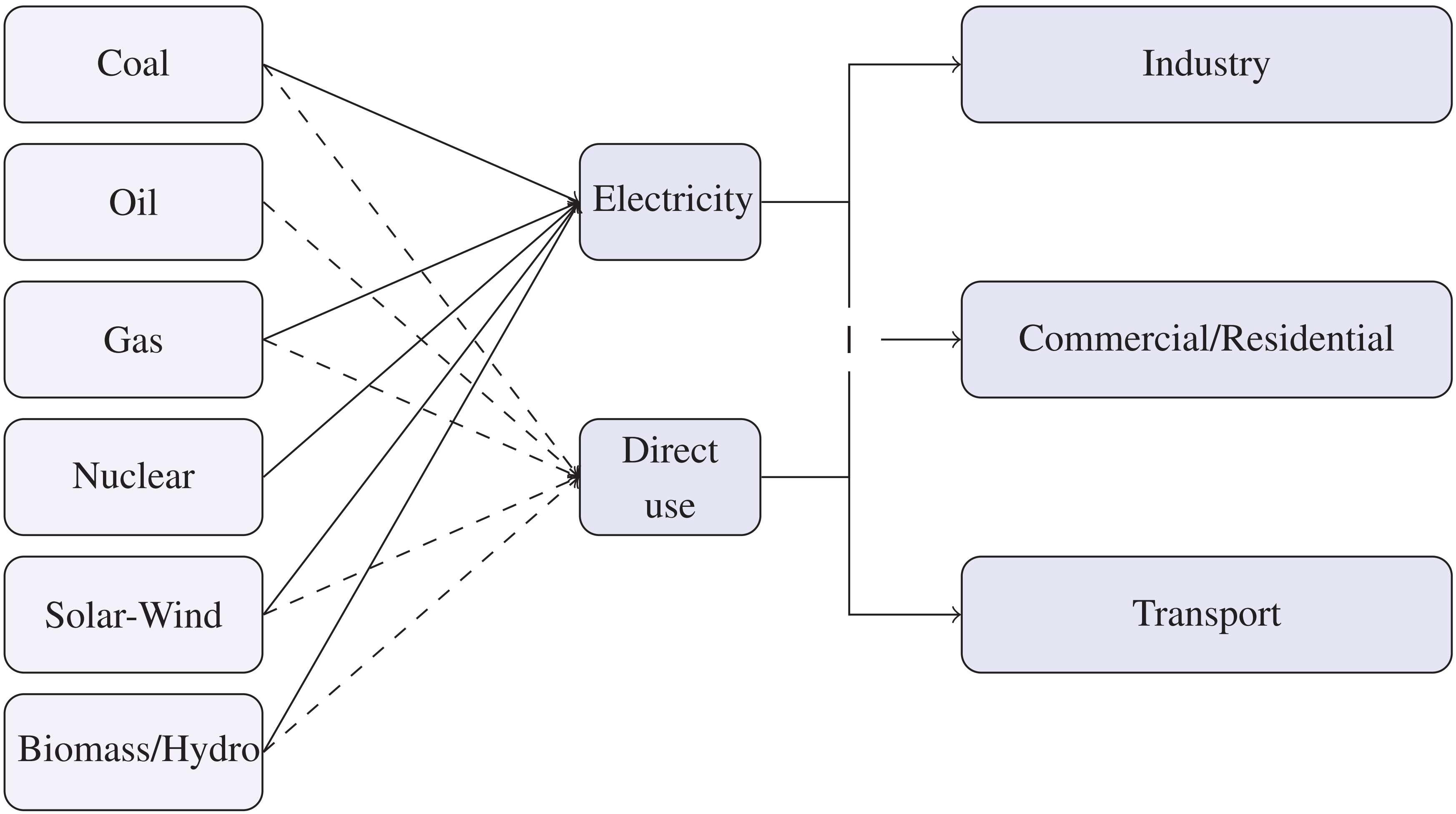
Questions to Answer

- CAN CHINA REDUCE COAL USE BY EXPANDING NUCLEAR?
- WILL NUCLEAR POWER CROWD OUT RENEWABLES?
- WILL A CARBON TAX BE NECESSARY AND HOW BIG?
- HOW DO LEARNING RATES AFFECT SUBSTITUTION OF COAL BY RENEWABLES?

Energy Sectors

- Energy resources:
- Coal, oil, natural gas
- Solar and wind
- Nuclear power
- Other renewables: biomass and hydro
- Energy-consuming sectors:
- Transport, industrial, residential/commercial

Schematic of the Model



Energy Supply Curves

- Fossil fuels have upward-sloping curves in each region calibrated from IEA data Graph
- They are tradable
- Transportation costs equal baseline price differentials

Extraction Cost of Fossil Fuels in Base Year (2013)

	North America	China	ROW
Coal (US$/ton)	87	105	96
Oil (US$/barrel)	50	52	30
Gas ($/MMBTu)	2.50	3.50	3

IEA (2014) and BP Statistics (2013)

Cost of Supplying Electricity: Coal and Gas

Cost in US$/MWh		
	Coal	Gas
North America	68	76
China	29	35
ROW	32	54

5% discount rate; IEA (2012)

Costs include investment and O&M

Cost of Supplying Electricity: Nuclear

	Cost in US$/MWh
North America	48
China	33
ROW	50

5% discount rate; IEA (2012)

Cost of Electricity from Solar/Wind: 90/MWh

Model Assumptions

- We divide renewables into wind/solar and hydro/biomass
- We fix nuclear either at IEA estimates or a complete freeze
- We fix generation from hydro/biomass because that is unlikely to grow significantly
- Learning by doing is modeled by cost reductions as a function of cumulative production

Modeling Learning by Doing

- The average cost of investment in electricity C_T, from solar and wind at date T is given by:

$$C_T = \alpha[\sum_{t=1}^{T} q_t]^{-b} \qquad (1)$$

- b: learning rate parameter, α: calibrated constant
- For a learning rate equal to 15%, the average cost decreases by $1-2^{0.15} = 11\%$ with doubling of production.
- Operation and maintenance costs are assumed to decrease by 1% annually.

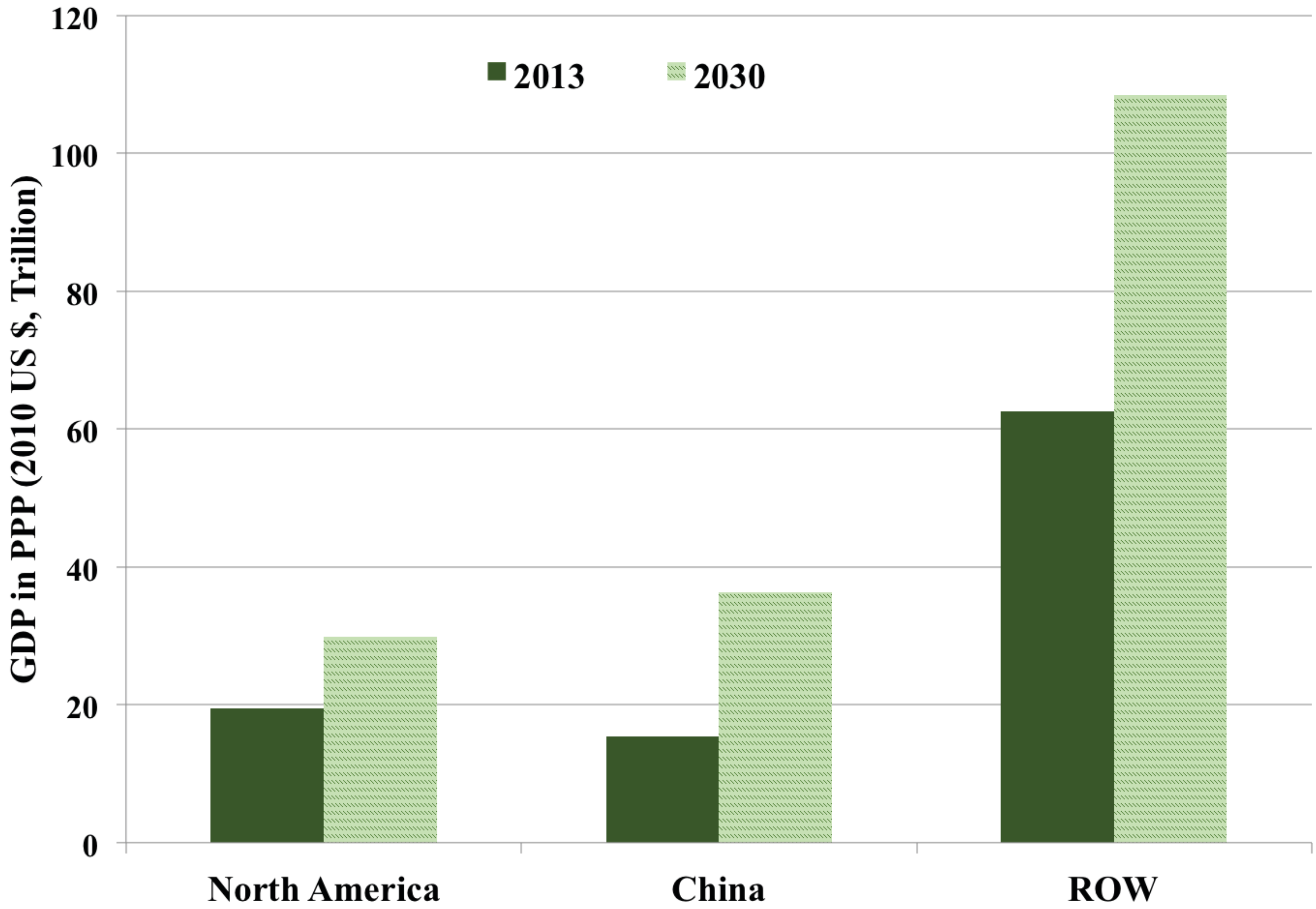
Final Energy Demand

- Sectoral demand is a function of regional GDP and the price of energy

$$D_{jr} = A_{jr} P_{jr}^{\alpha_{jr}} Y_r^{\beta_{jr}}$$

- where j represents sector and r the region
- Y is the level of GDP, taken as given.

Annual Income Projections by Region

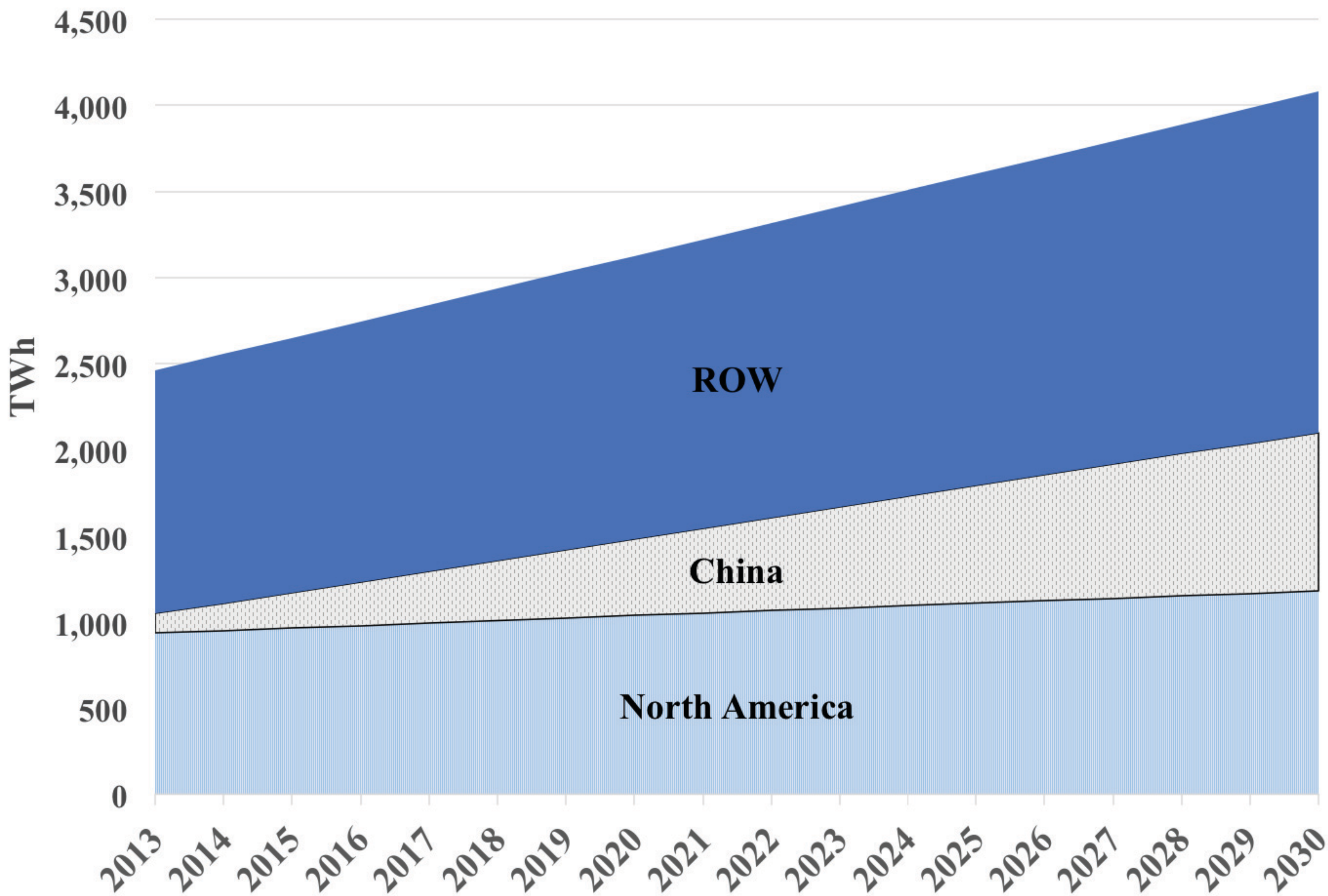


Source: (EIA, 2014)

Scenarios

- We define four models:
- Freeze in Chinese nuclear capacity at 112 TWh
- Nuclear Growth to reach 1029 TWh in 2030
- Impose a 65% intensity reduction from 2005-2030
- No intensity reduction

Planned Nuclear Growth



Growth in Nuclear Power: Regional Targets

	Nuclear Generation (TWh)	
	2013	2030
North America	936	1,179
China	112	1,029
ROW	1,412	1,979
World	2,460	4,080

Calculations based on IAEA (2014) projections.

Results

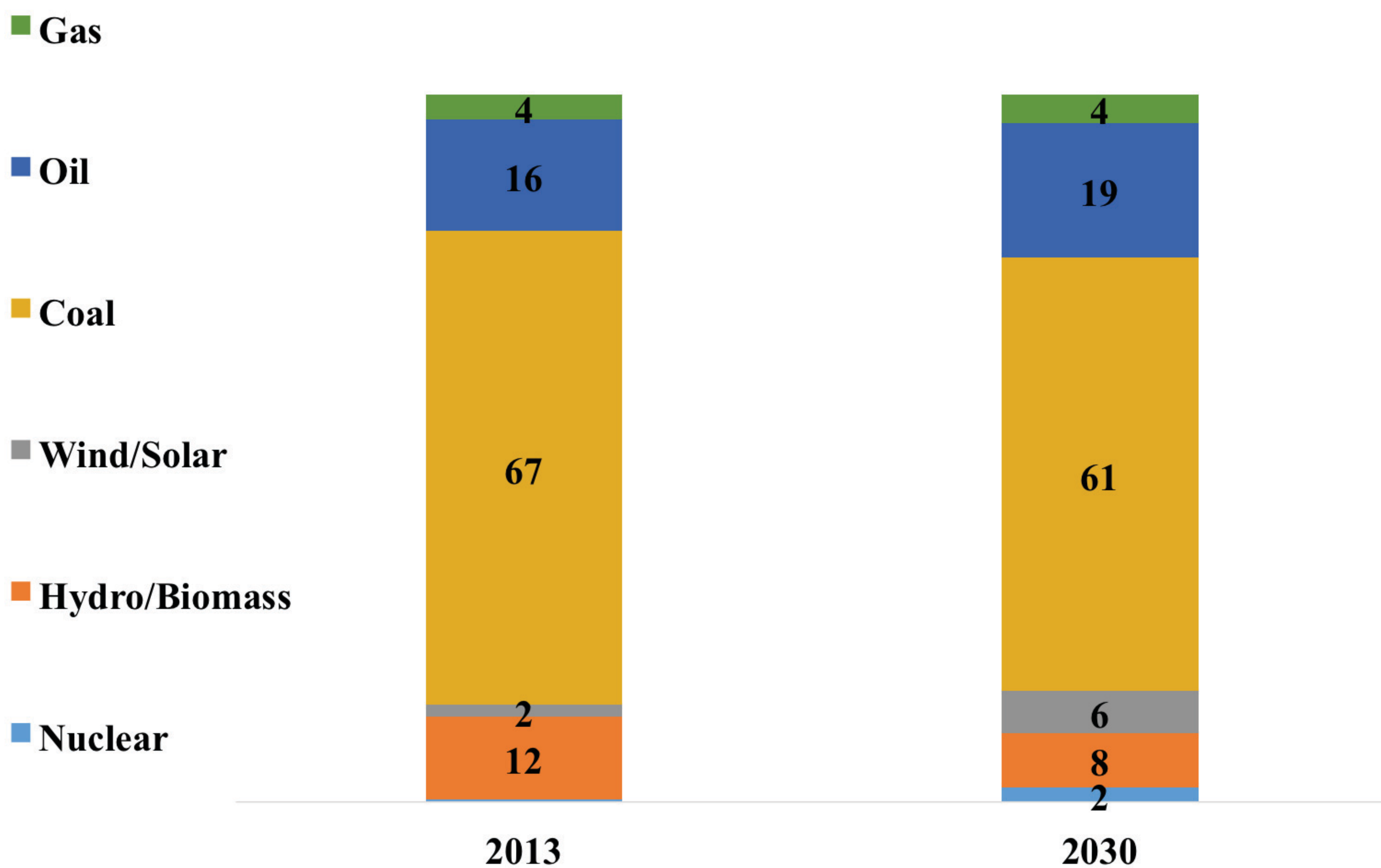
- First, We show baseline results: Nuclear Growth, No Intensity Target
- Next, we compare the four models

Baseline Results : CO2 Emissions and Carbon Intensity 2013-2030

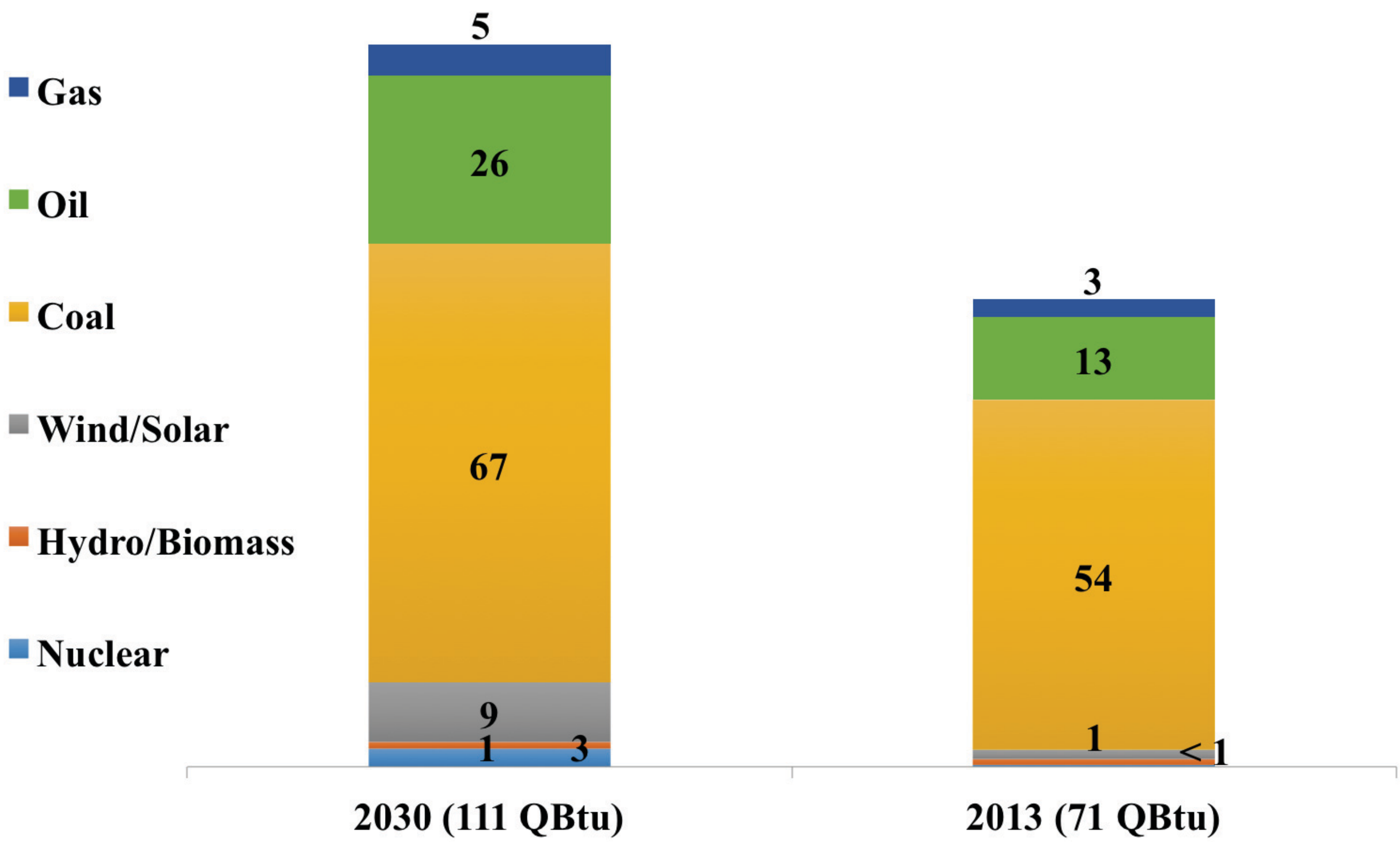
	CO2 Emissions (Btons CO2)	Carbon Intensity (kg CO2/$)
2013	9.83	0.98 (-8%)
2030	15.80	0.62 (-42%)

Emissions increase by 60% during 2013-30; Carbon Intensity in 2005 = 1.07.
Reductions reported relative to 2005. Paris Commitment: 65% reduction

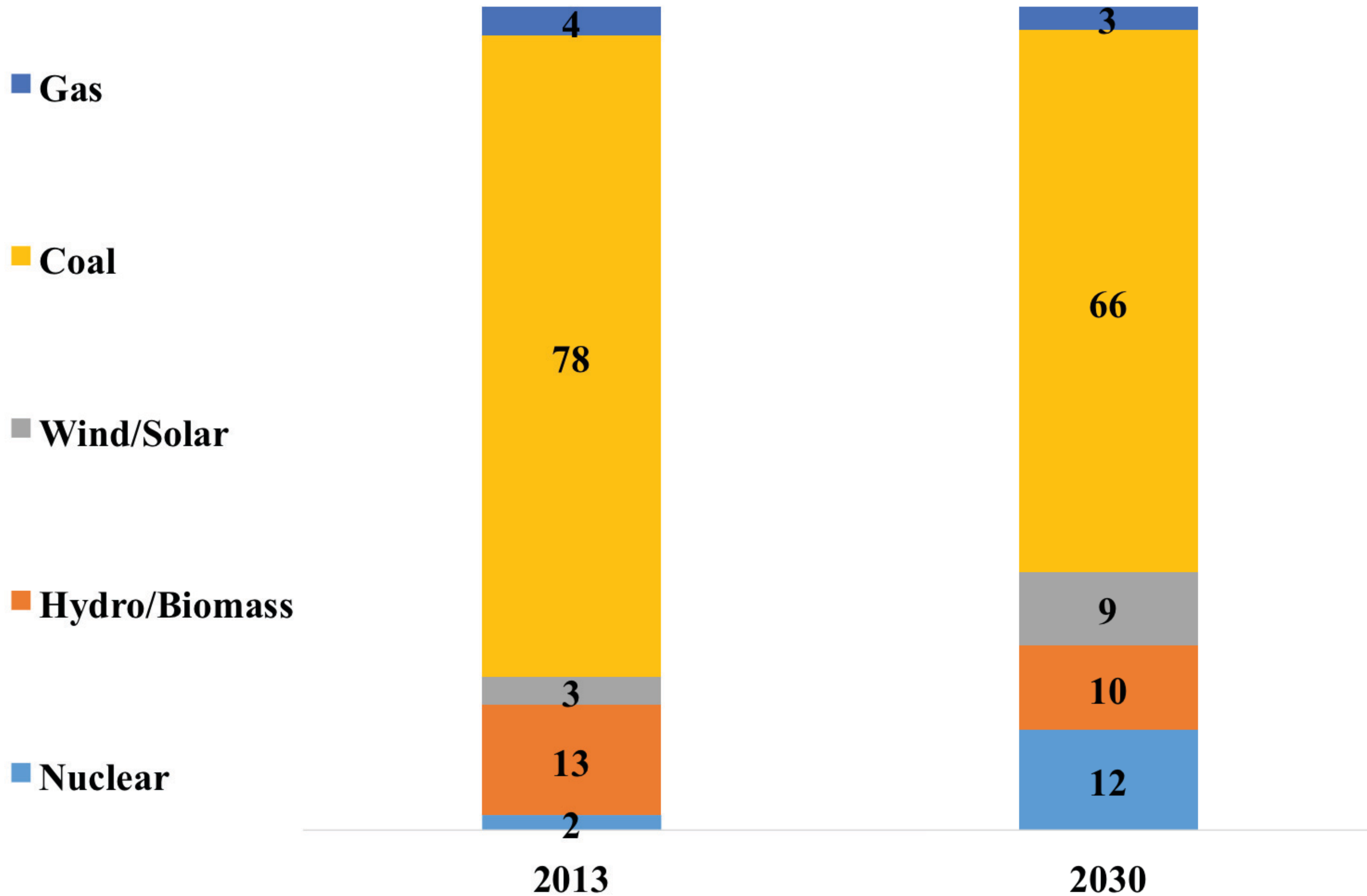
Share of Fuel in Energy Output (2013-2030)



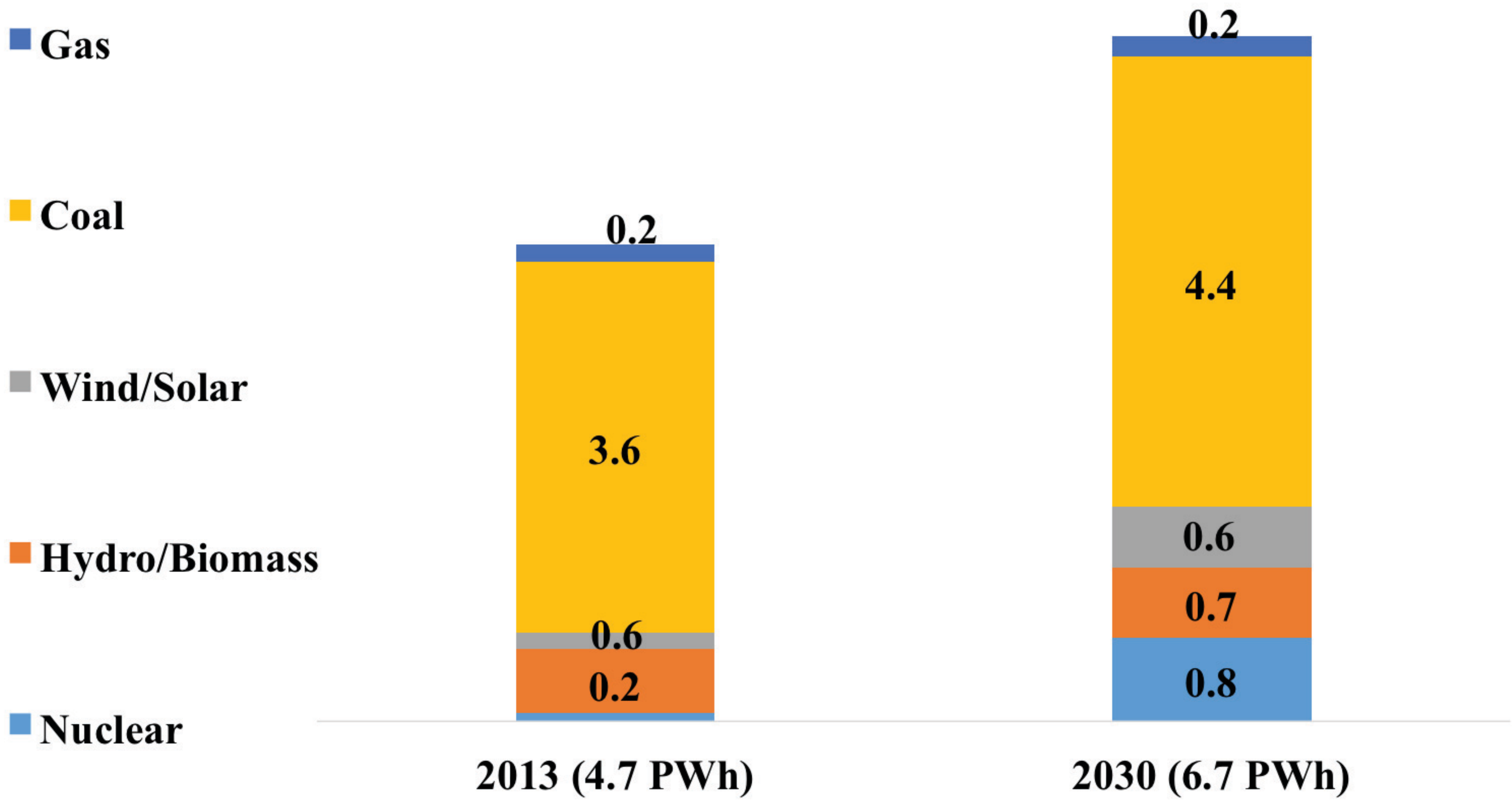
Energy Output by Fuel (2013-2030)



Share of Fuel in Electricity Generation (2013-2030)



Electricity Output by Fuel (2013-2030)

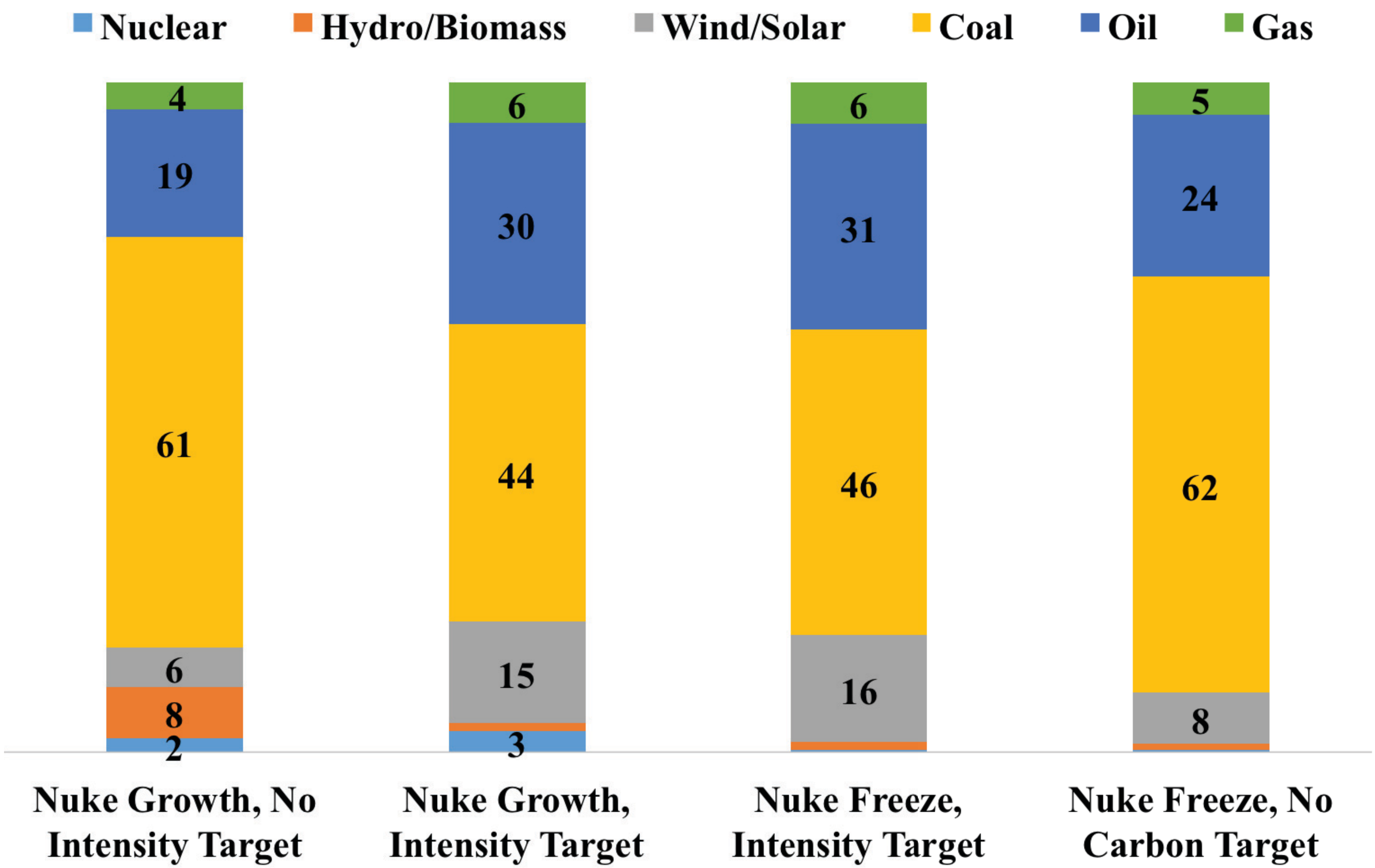


Results: CO2 Emissions and Carbon Intensity in 2030

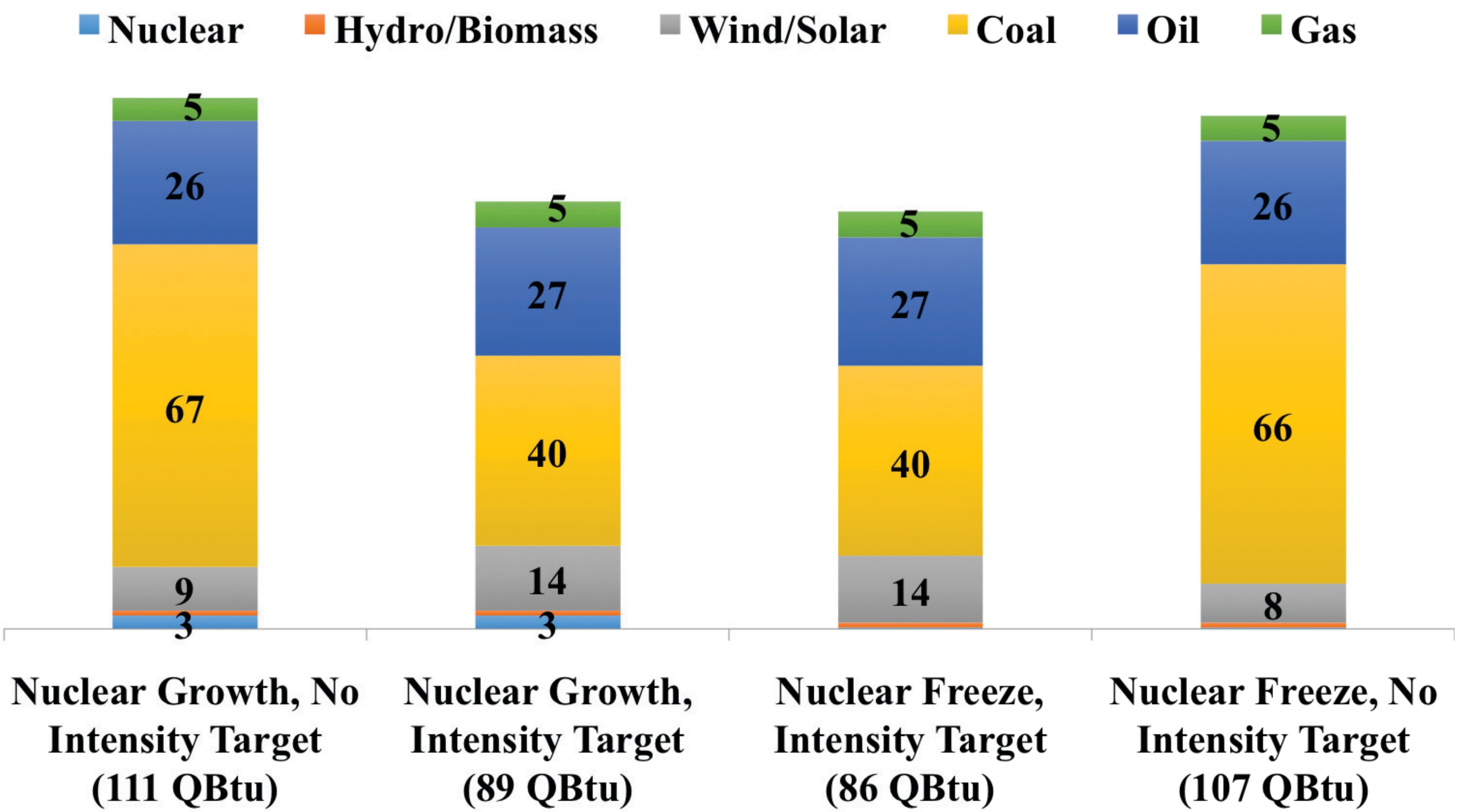
	CO2 Emissions (Billion tons of CO2)	Carbon Intensity (kg CO2/$)	Carbon Tax ($/ton)
Nuclear Growth, No Intensity Target	15.80	0.62 (-42%)	–
Nuclear Growth, with Target	9.62	0.38 (-65%)	74
Nuclear Freeze, No Target	15.20	0.61 (-43%)	–
Nuclear Freeze, with Target	9.62	0.38 (-65%)	75

Carbon Intensity in 2005 = 1.07. Reductions reported relative to 2005. China's Paris Commitment: 65% reduction from 2005 levels.

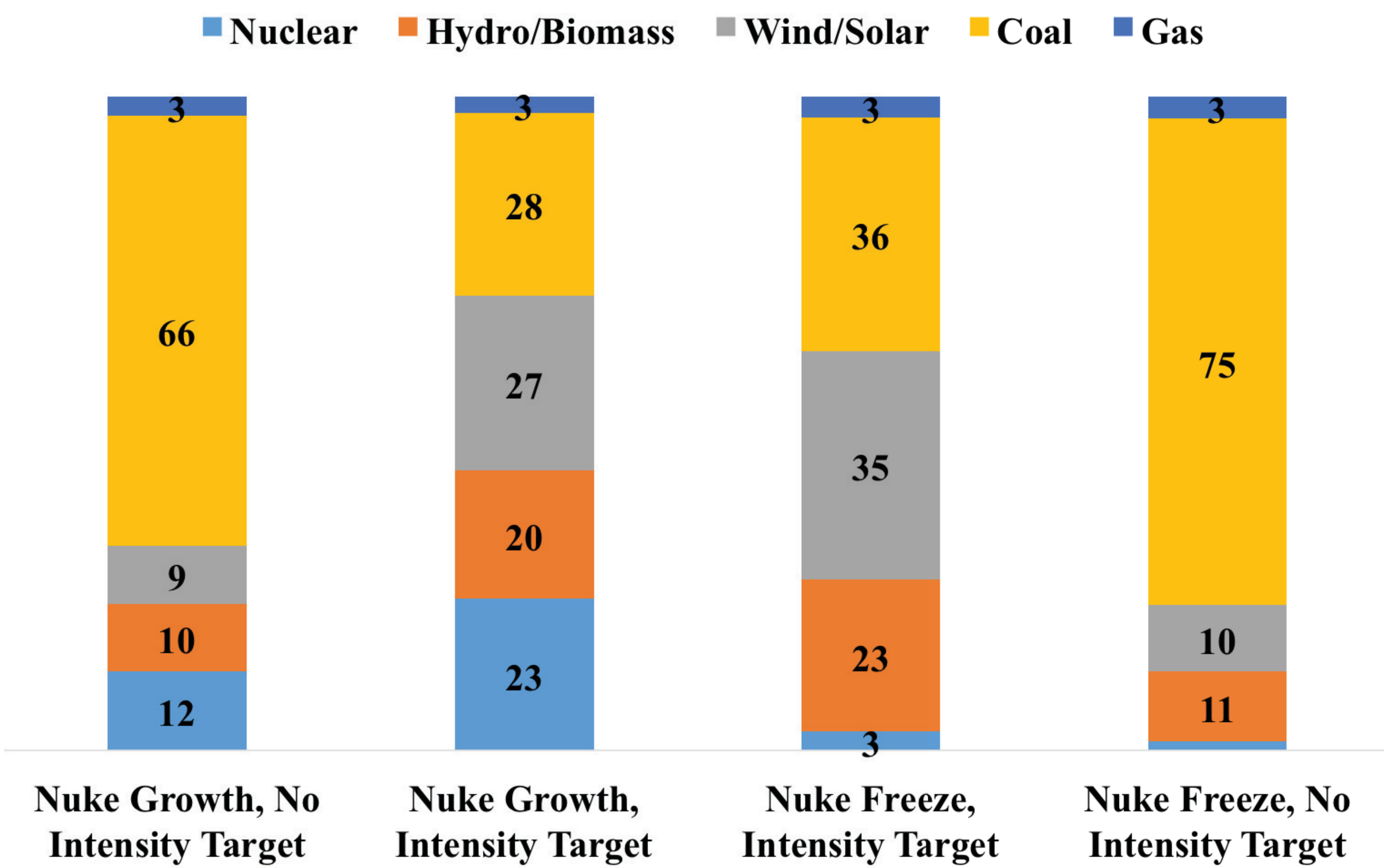
Share of Fuel in Energy Output (2030)



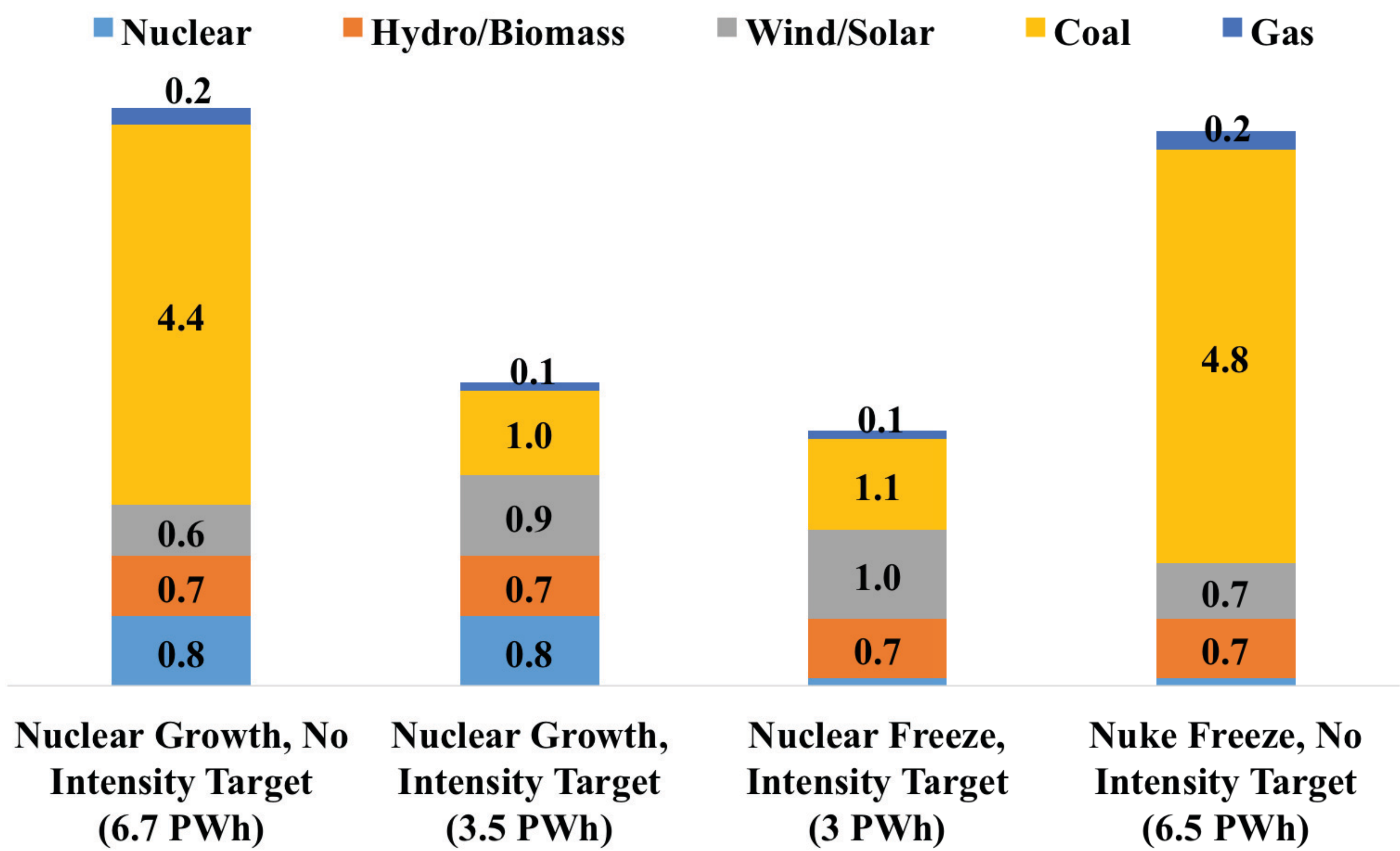
Energy Output by Fuel (2030)



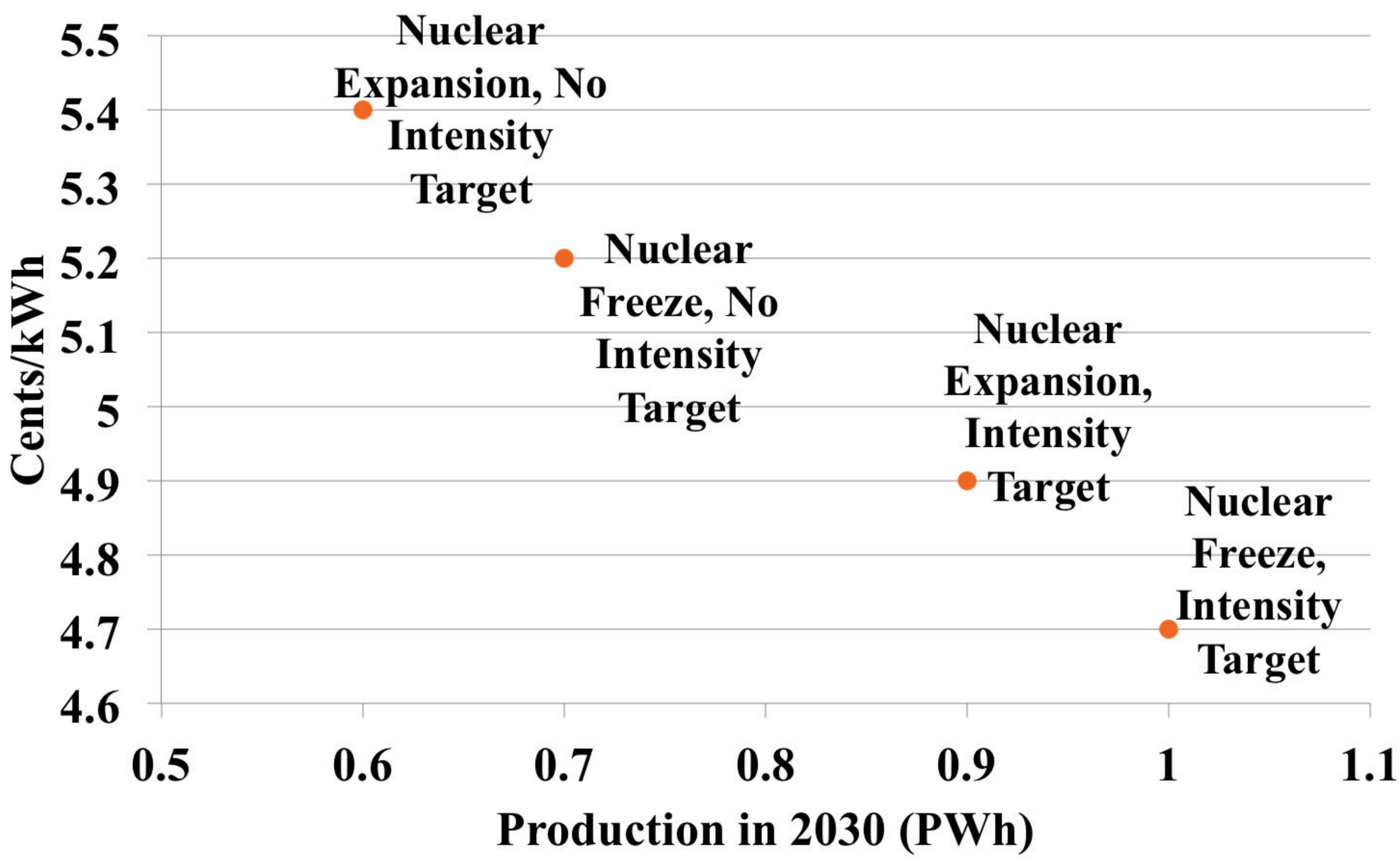
Share of Fuel in Electricity Output (2030)



Electricity Output by Fuel (2030)



Cost of Generating Electricity from Solar-Wind in 2030



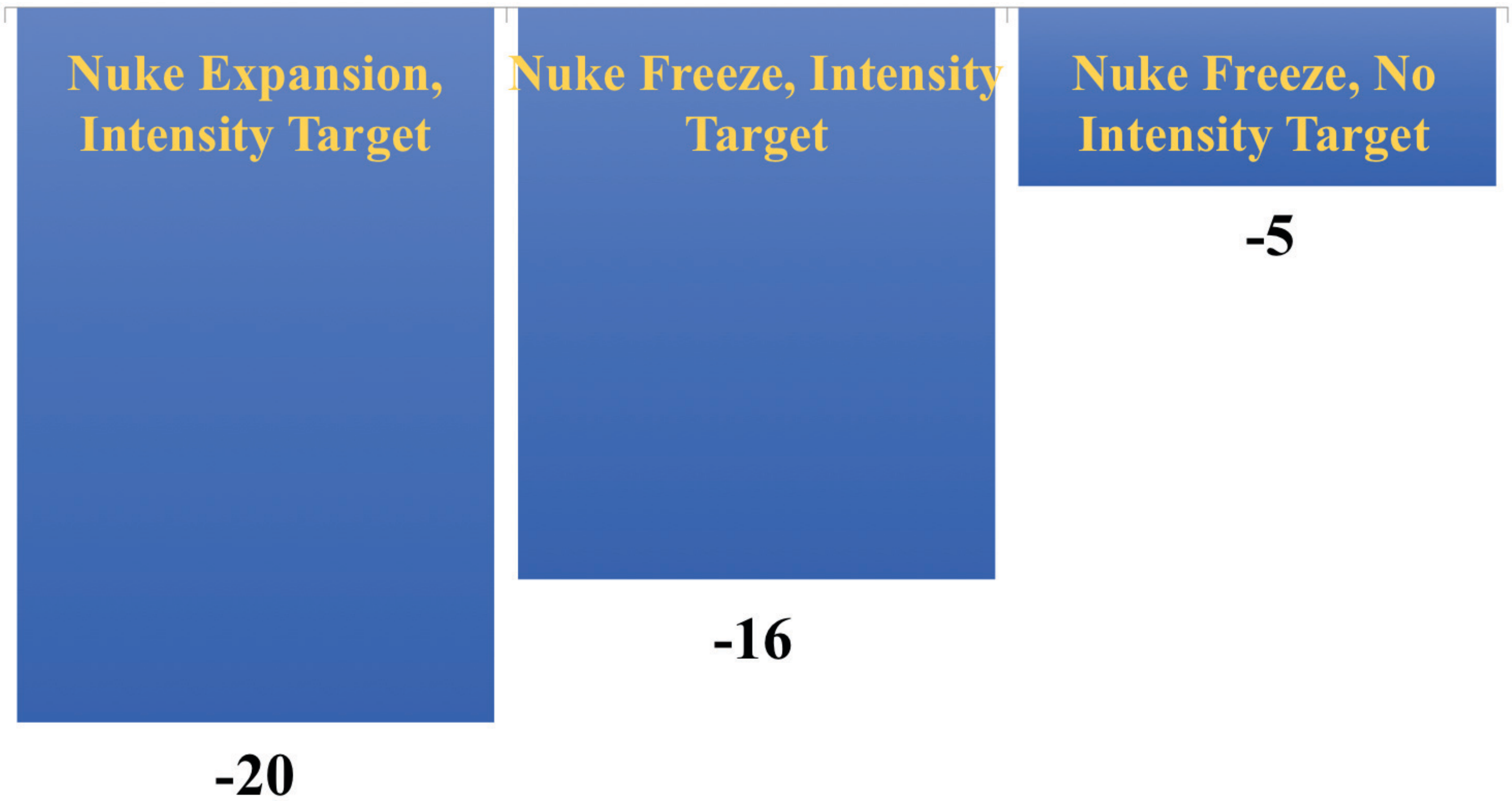
Cost in 2013 is 9 cents per kWh

Unit Cost of Generating Electricity from Renewables in Model (2030)

	Power Generation (PWh)	Average Cost (c/KWh)
Nuclear Growth, No Intensity Target	0.6	5.4
Nuclear Freeze, No Target	0.7	5.2
Nuclear Growth, With Target	0.9	4.9
Nuclear Freeze, With Target	1.0	4.7

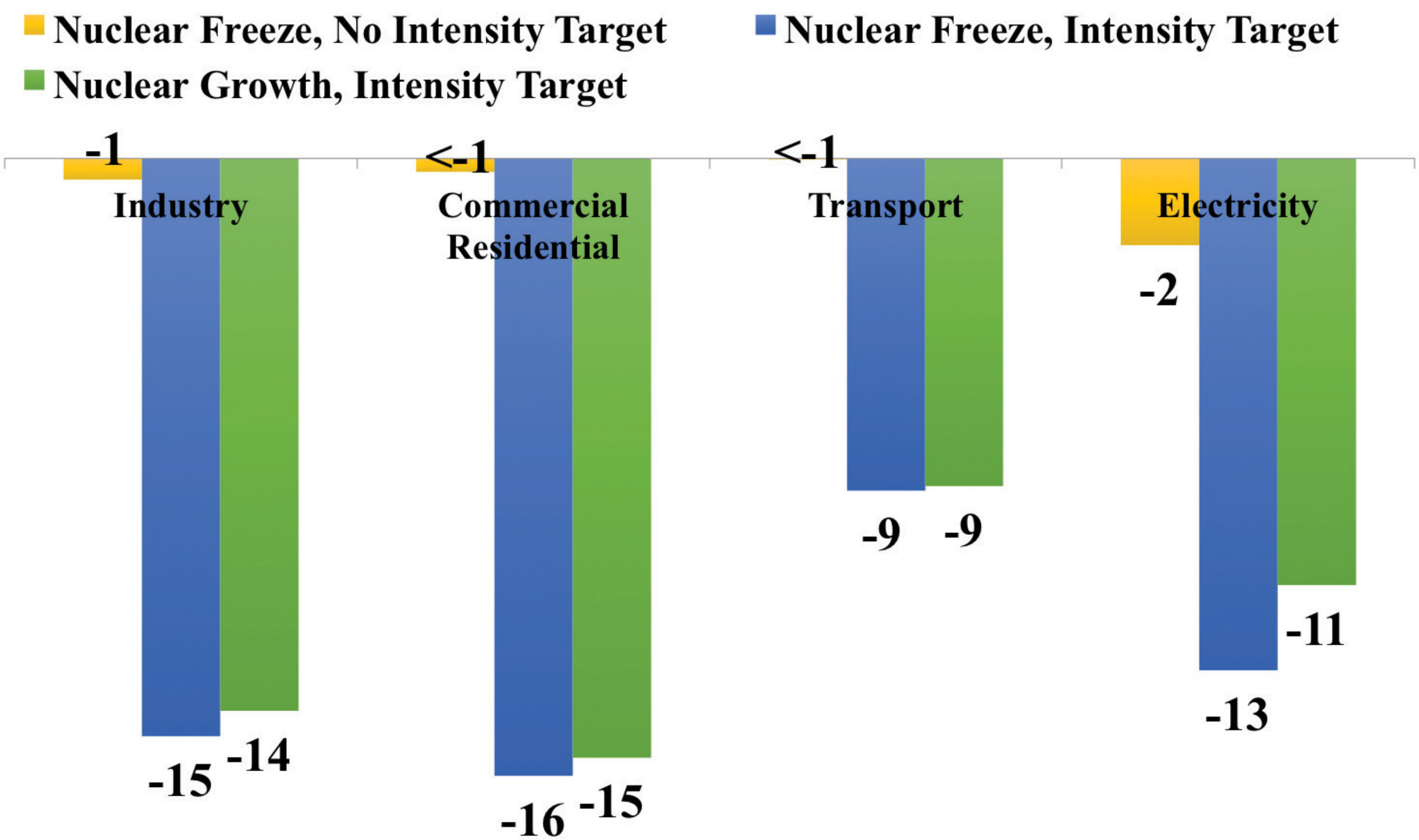
Note: Costs are model outcomes.

Percent Change in Total Surplus (2030)



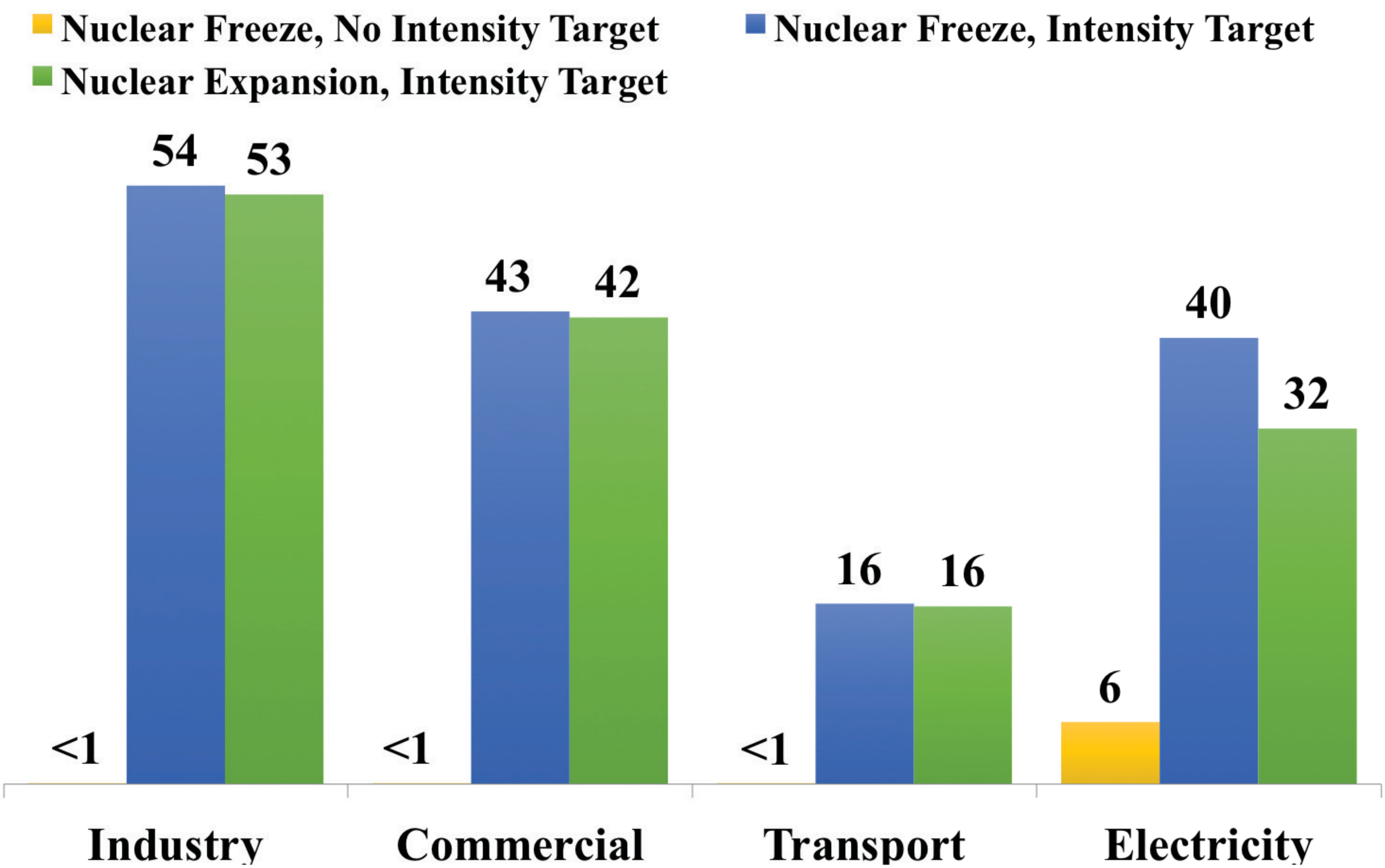
Percentage change compared to Nuclear Expansion, No Intensity Target

Change in Final Demand for Energy (2030)



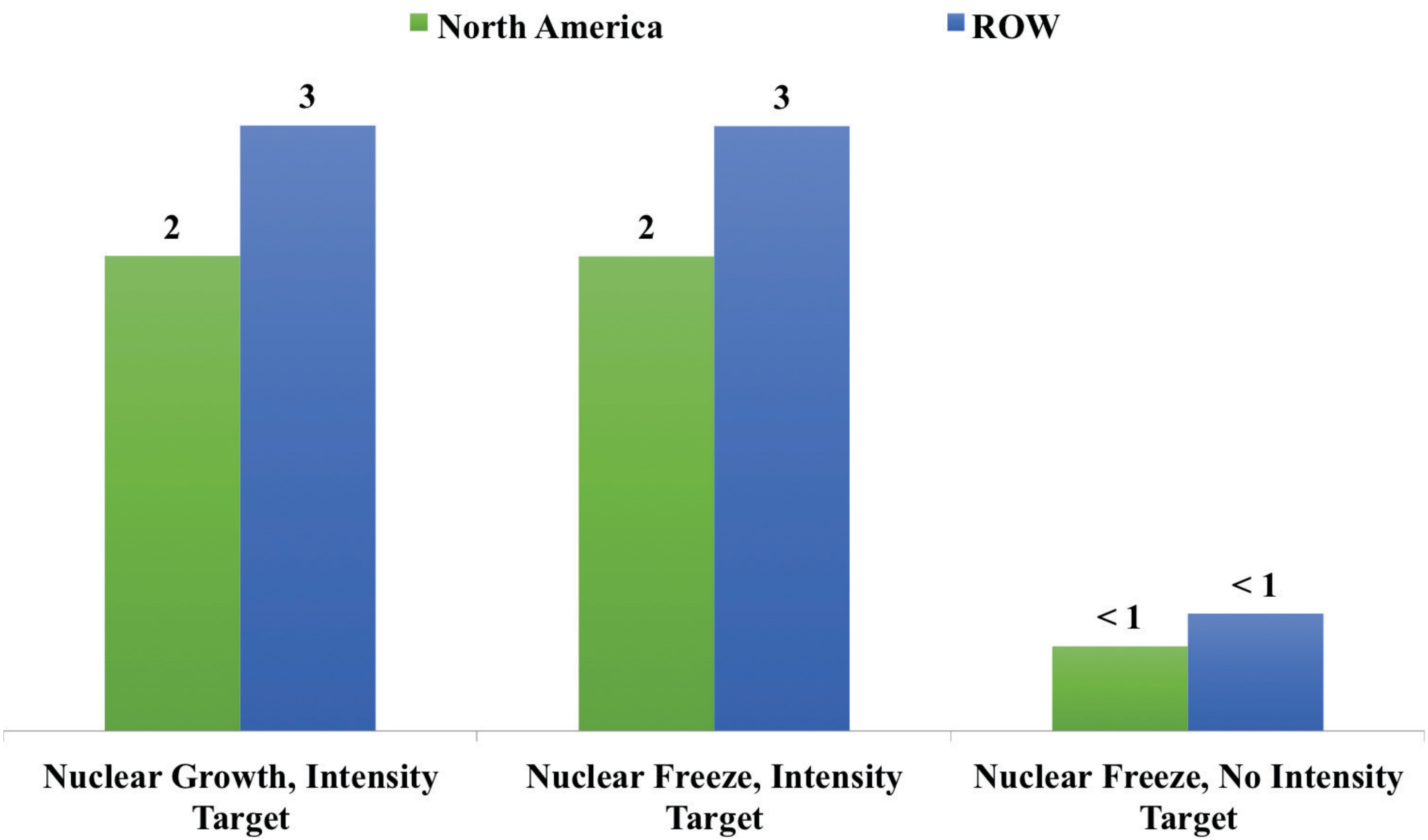
Percentage change compared to Nuclear Expansion, No Intensity Target

Change in Final Price for Energy (2030)



Percentage change compared to Nuclear Expansion, No Intensity Target.

Change in Carbon Emissions in North America and ROW

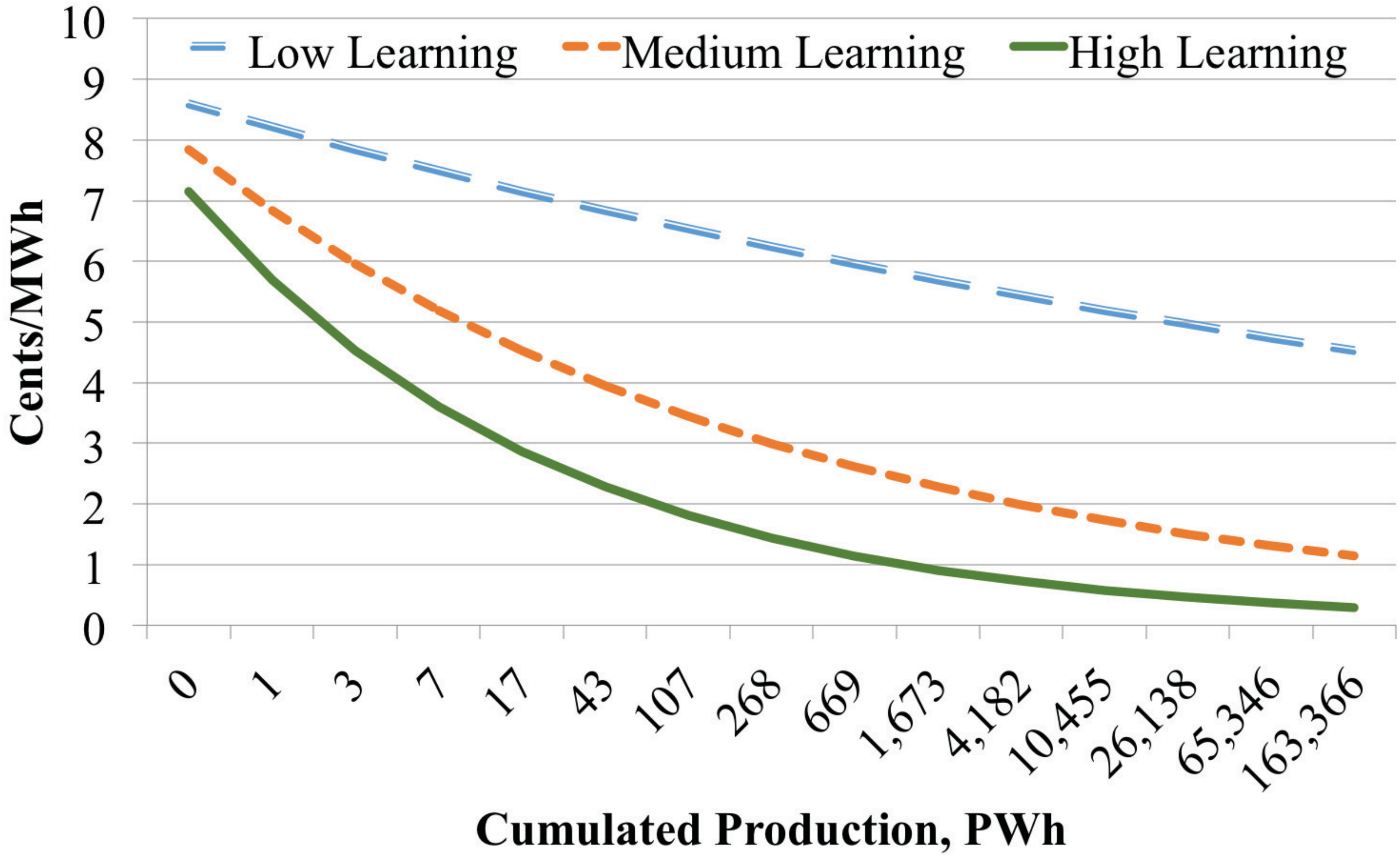


Percentage change compared to Nuclear Growth, No Intensity Target

Changing the Learning Rate

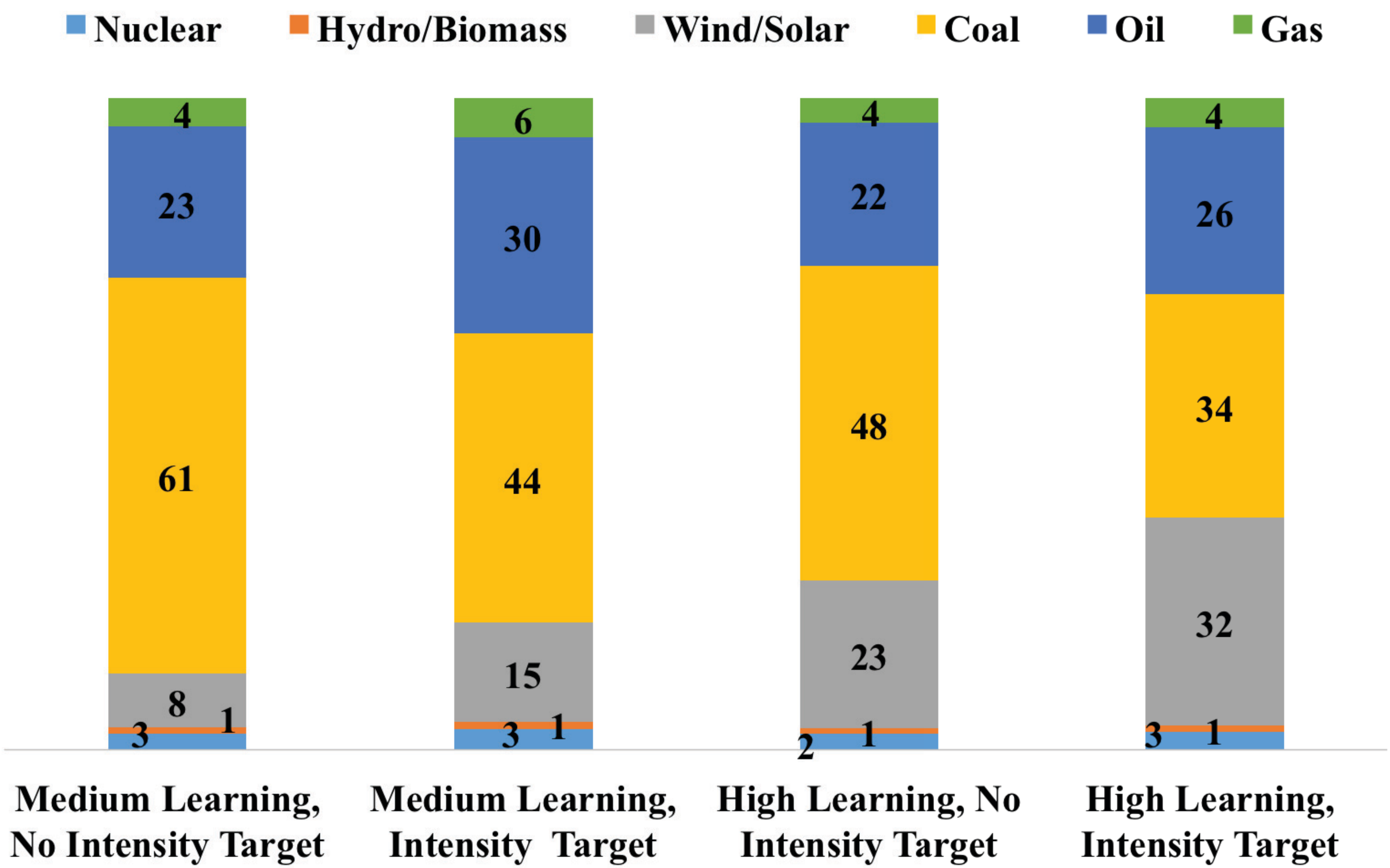
- Until now, average cost of renewables decreases by 11% with doubling of production
- We now model a higher learning rate, where cost declines by 20% with doubling

Assumptions on Learning by Doing

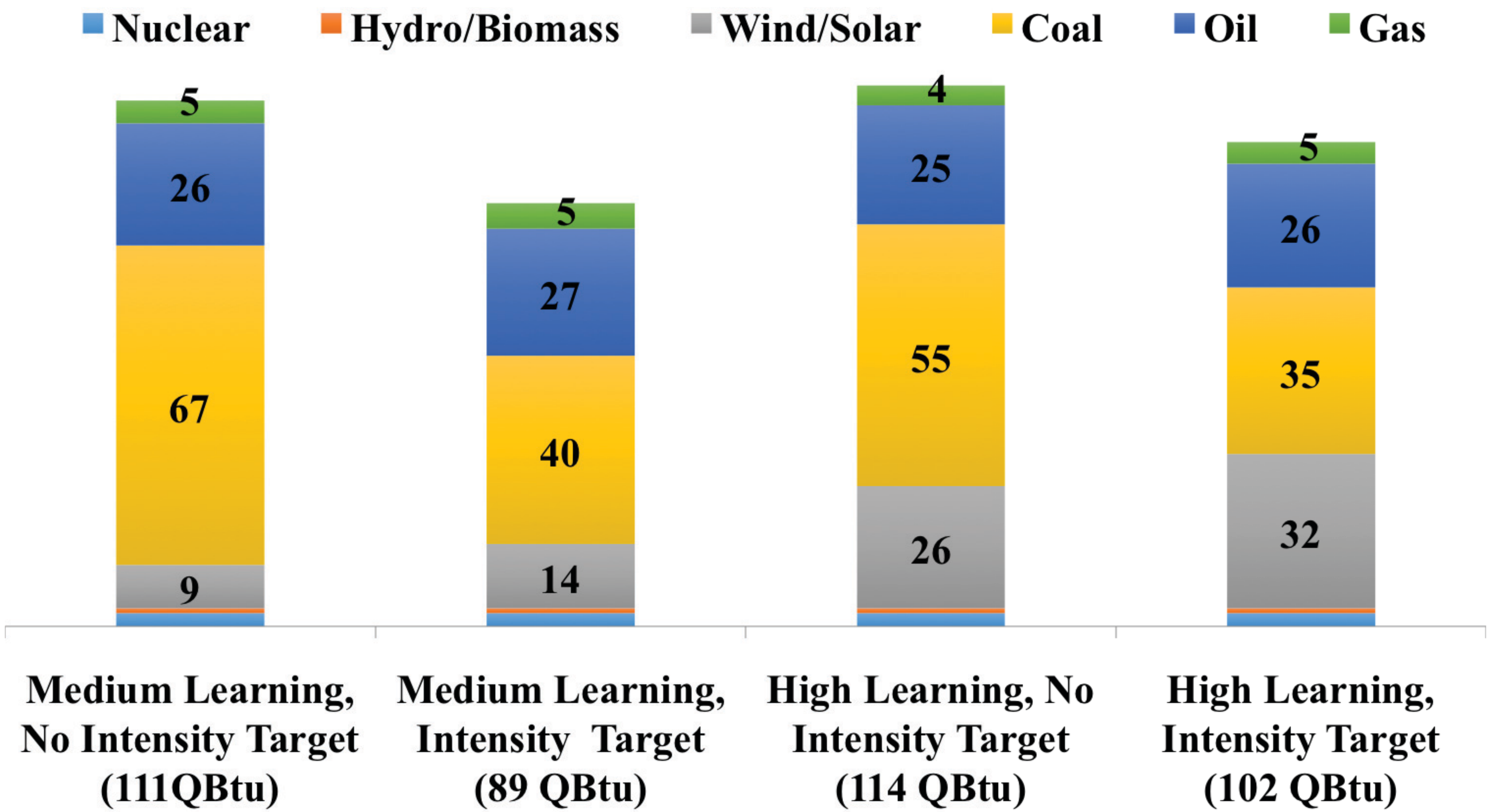


Source: IEA (2014)

Share of Fuel in Energy Output (2030): Learning Rates make a big difference



Energy Output by Fuel (2030)



Sensitivity Analysis

- China's Paris Commitment in terms of the share of non fossils in the energy mix in 2030 is met even without any carbon tax
- However, a carbon tax is needed to meet the intensity target

Carbon Emissions, Carbon Intensity and Tax, 2030

	CO2 Emissions (Btons CO2)	Carbon Intensity (kg CO2/$)	Carbon Tax ($/ton CO2)
Medium Learning, No Intensity Target	15.80	0.62 (-42%)	–
Medium Learning, Intensity Target	9.62	0.62 (-42%)	74
High Learning, No Intensity Target	13.27	0.52 (-52%)	–
High Learning, Intensity Target	9.62	0.52 (-52%)	50

Carbon Intensity in 2005 = 1.07. These reductions (numbers in parenthesis) are relative to 2005. China's Paris Commitment: 65% reduction from 2005 levels. Tax in 2010 USD.

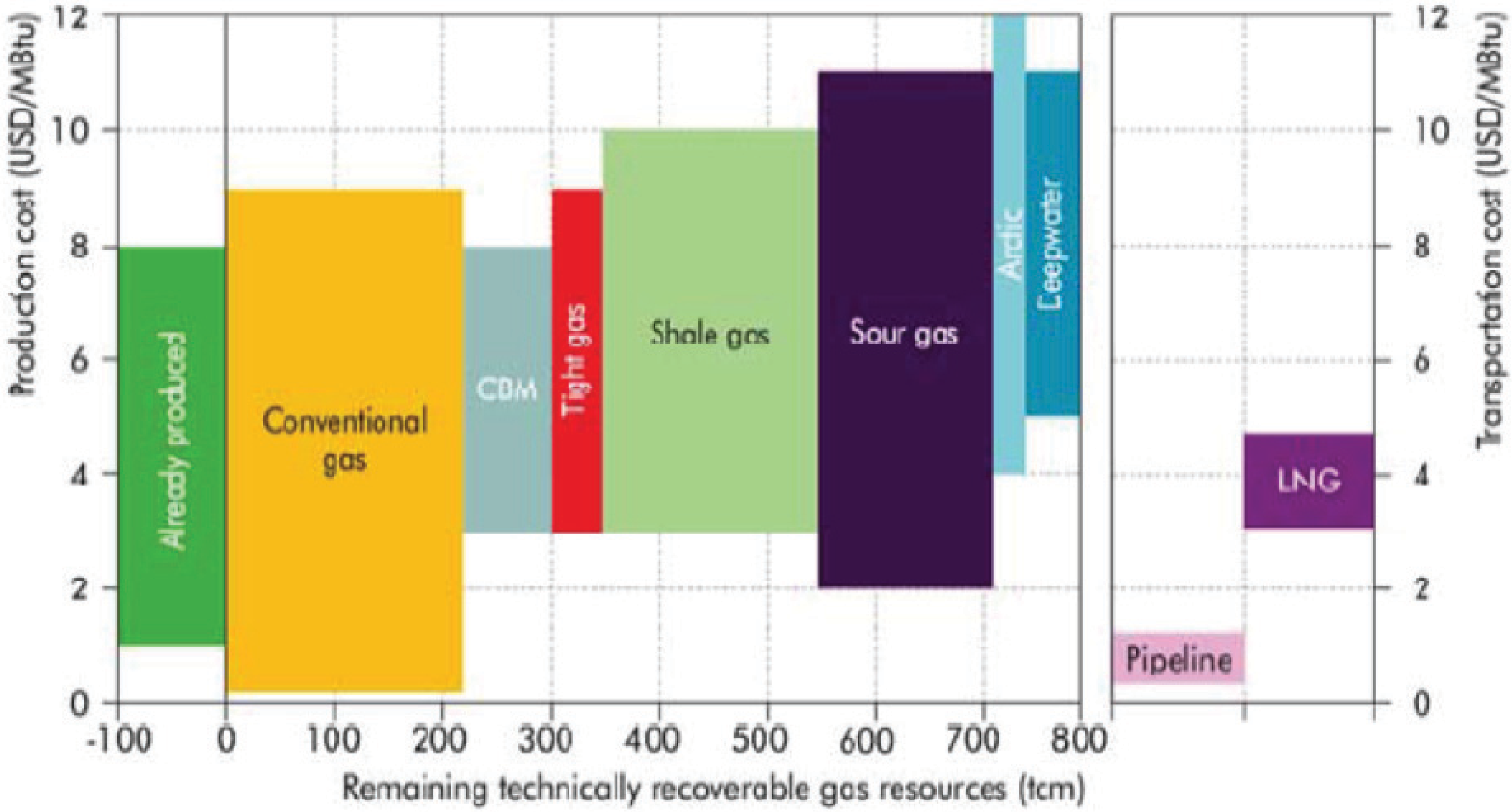
Main Results

- Big Reductions in Coal Use but only with Carbon Tax
- Nuclear Alone Does not Deliver
- Nuclear does Crowd Out Renewables
- The implicit tax to reach the carbon intensity goal is about 75 US dollars per ton.
- Chinese policy has second order effects on other regions

Things To Do

- Include Spillovers from renewable energy use in China on rest of the world - include Trade in Renewables
- Include declining efficiency of solar with increased adoption
- Include Learning in other technologies

Long Run Supply Curve for Natural Gas



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