Climate and the Nuclear Future

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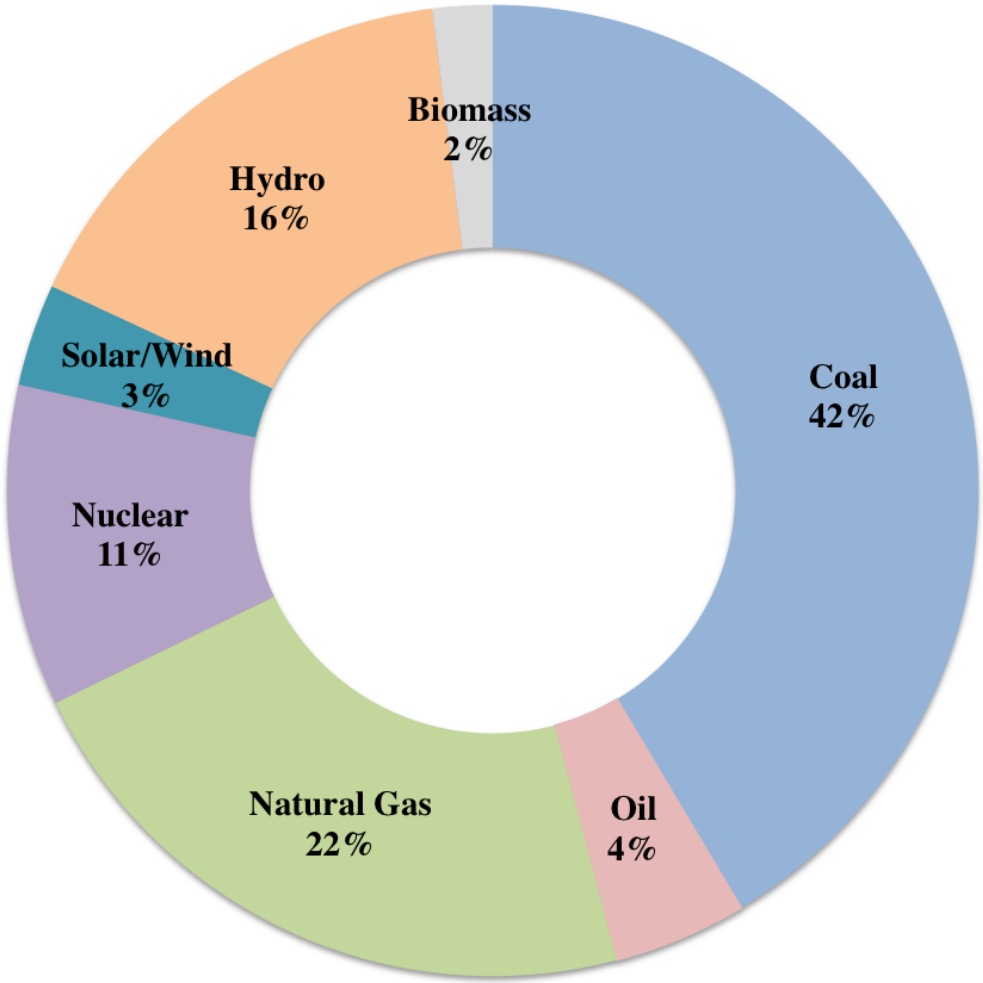
Plan of Talk

- Discuss the Role of Nuclear Power Today
- Preliminary Output from a Modeling Exercise
- Provide Perspective on Nuclear in the Long Run

World Electricity Output by Fuel in 2013



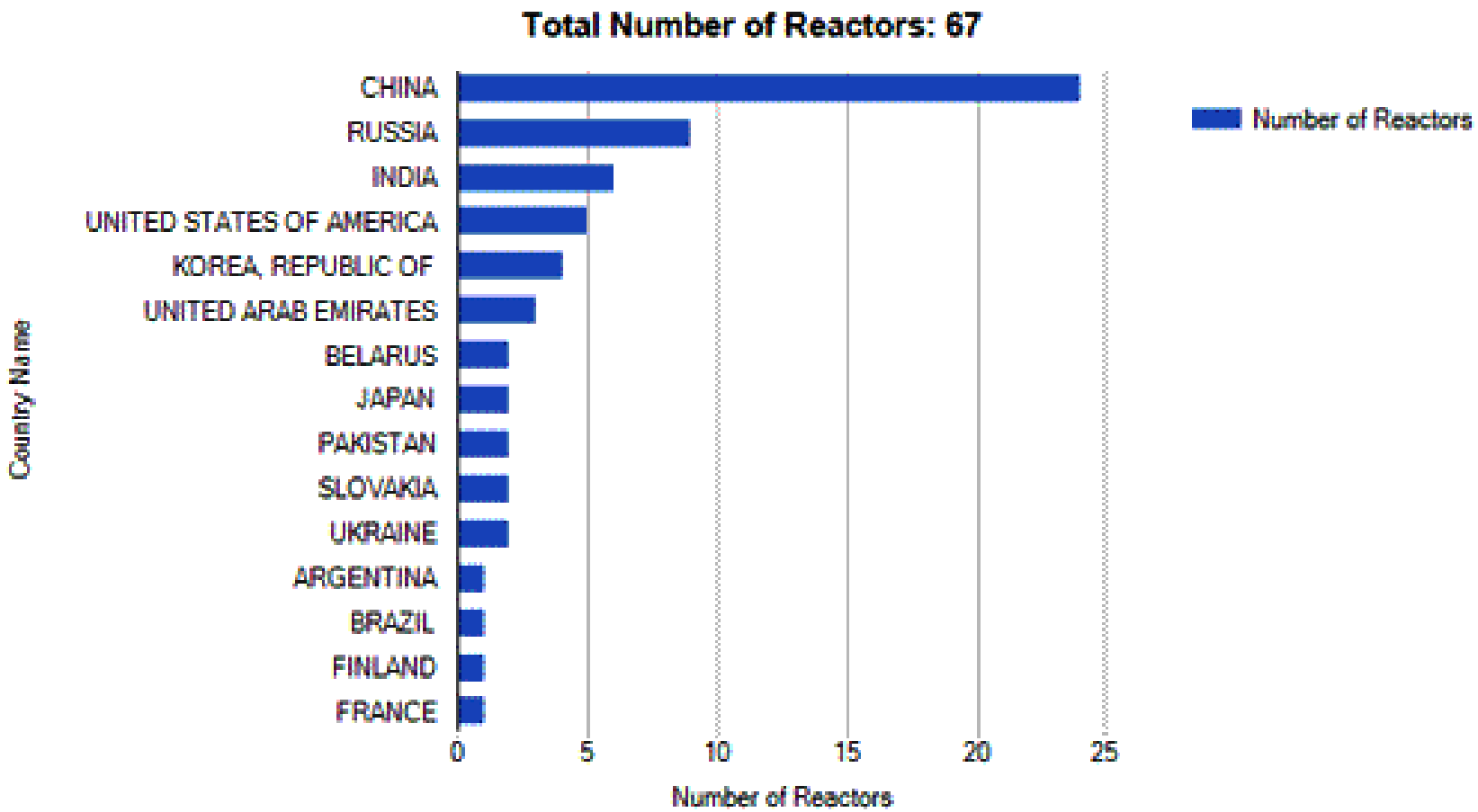
Total Production: **23,307 TWh** (IEA 2015).

Nuclear Capacity by Country, June 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

Number of Reactors Under Construction, June 2015



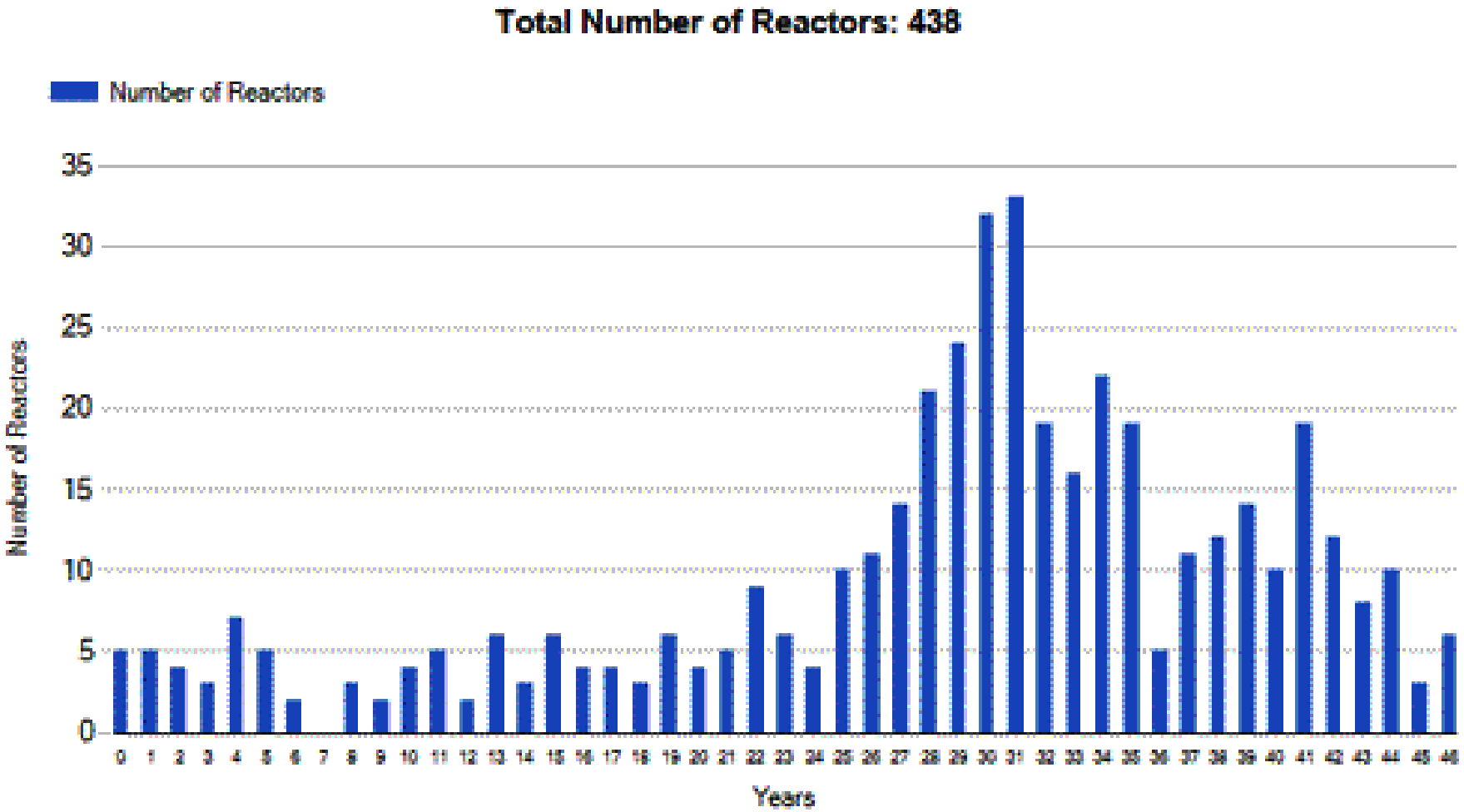
Nuclear Power 101

- 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
- This translates into an annual growth of power supply from nuclear at 95.3 TWh
- Allocated according to share of plant construction by region
- China: 50%, ROW: 35% and North America: 15%

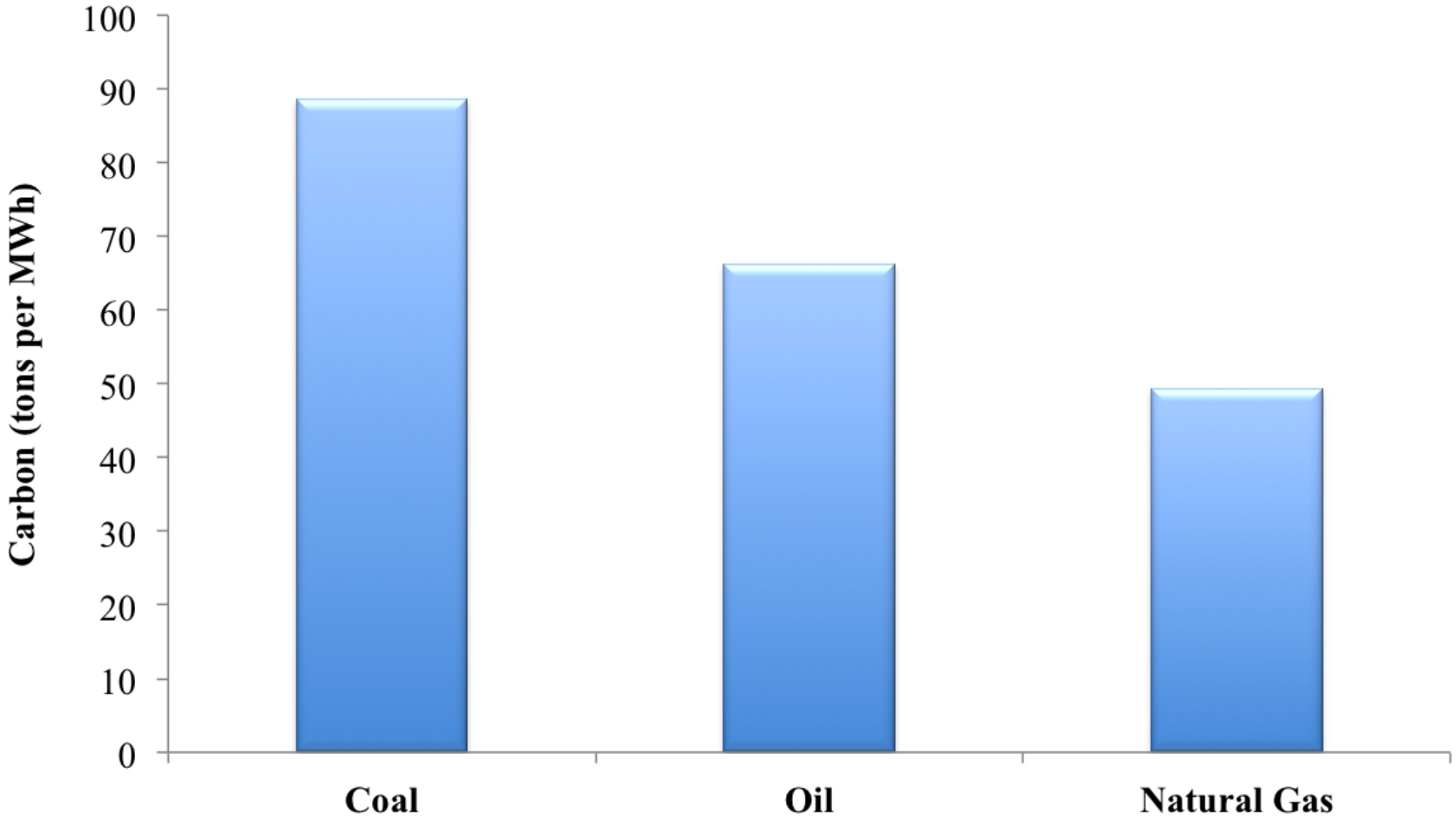
Nuclear Power 101

- For China, this means annual growth of 47.6 TWh
- In 2014, Chinese nuclear output was 124 TWh

Reactors by Age, June 2015



Carbon Content of Fossil Fuels



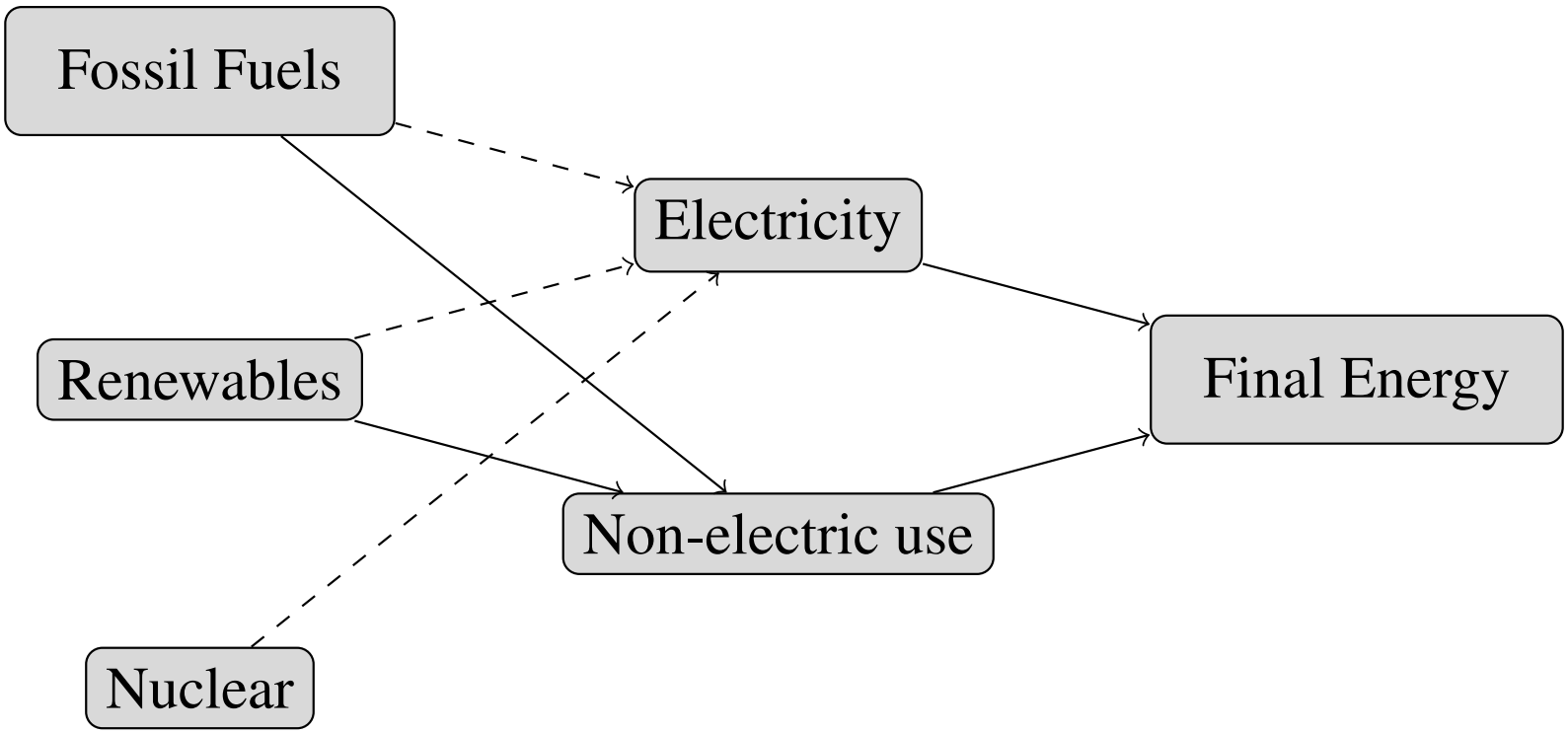
Objectives of the Paper

- Compare Planned Capacity vs a Moratorium on Nuclear expansion
- Effect on Coal Use, Carbon Emissions and Leakage
- Focus on Chinese Energy Use

Methodology

- Empirically calibrated dynamic partial equilibrium model of energy markets from 2011 to 2030
- Regions
    - China
    - North America (US, Canada and Mexico)
    - Rest Of the World (ROW)
- Energy inputs
    - Coal, oil, natural gas
    - Renewable energy aggregated
    - Nuclear power
- Energy-consuming sectors
    - Transport, industrial, residential/commercial

Schematic of the model



Energy Supply

- Energy input production
  - Fossil fuels have upward-sloping curves in each region: Graph

$$C_{ir}^{t}(s_{ir}^{t}) = \chi_1 + \chi_2\{\frac{\sum_{\theta=0}^{t} s_{ir}^{\theta}}{\bar{S}}\}^{\chi_3}$$

  - Coal is cheap and abundant
- Transportation costs equal baseline price differentials
- Final energy production
  - Nested CES production function

Extraction cost of fossil fuels

	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);

MMBTu: Million British Thermal Units

Cost of Supplying Electricity by Region/Fuel

Cost in US$/MWh				
	Coal	Gas	Nuclear	Renewables
North America	68	76	72	70
China	29	35	50	30
ROW	32	54	60	52

5% discount rate; IEA (2012) and Chakravorty et al. (2012)

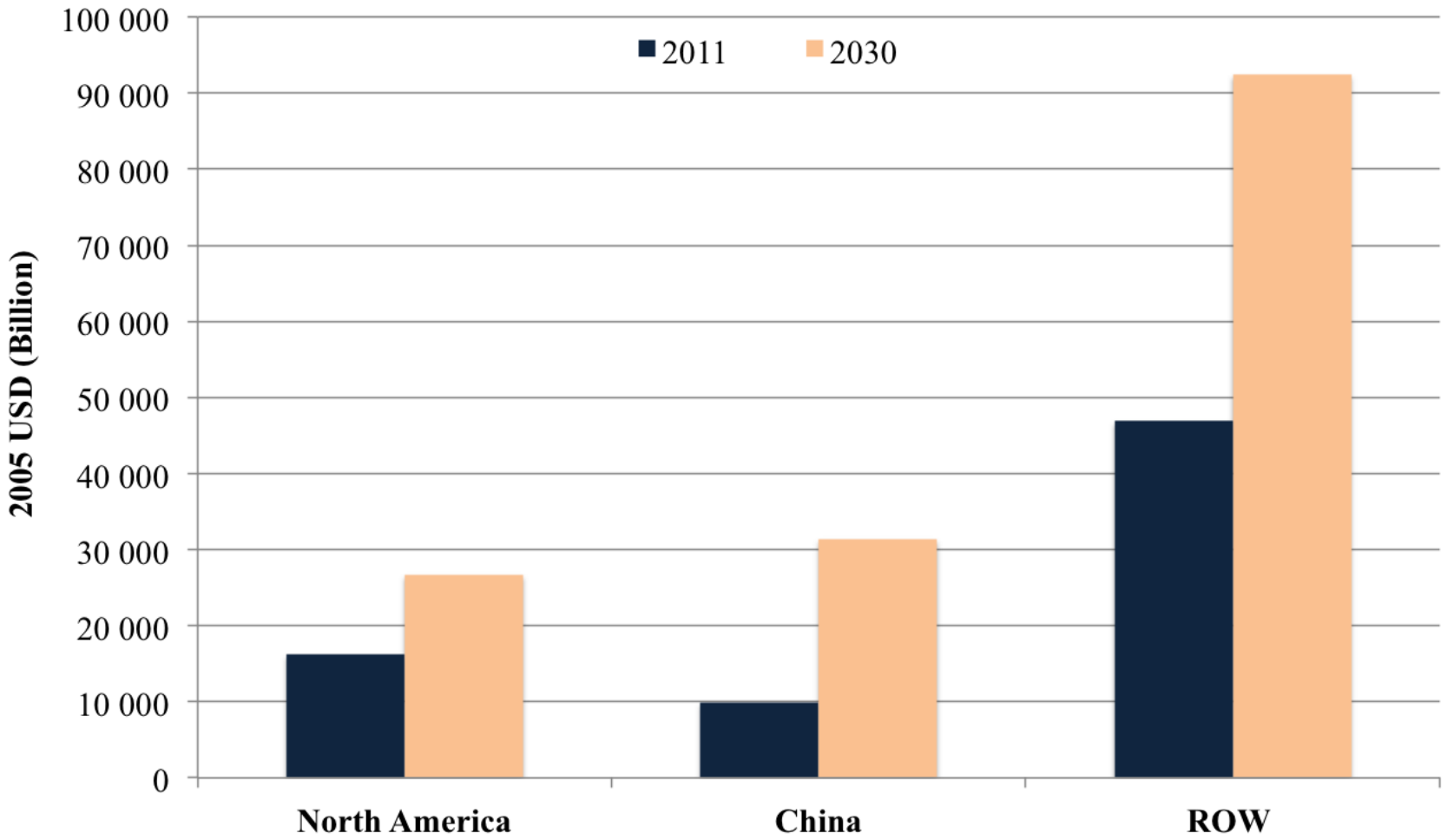
Sectoral Final Energy Demand

- 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

Annual Income Data by Region

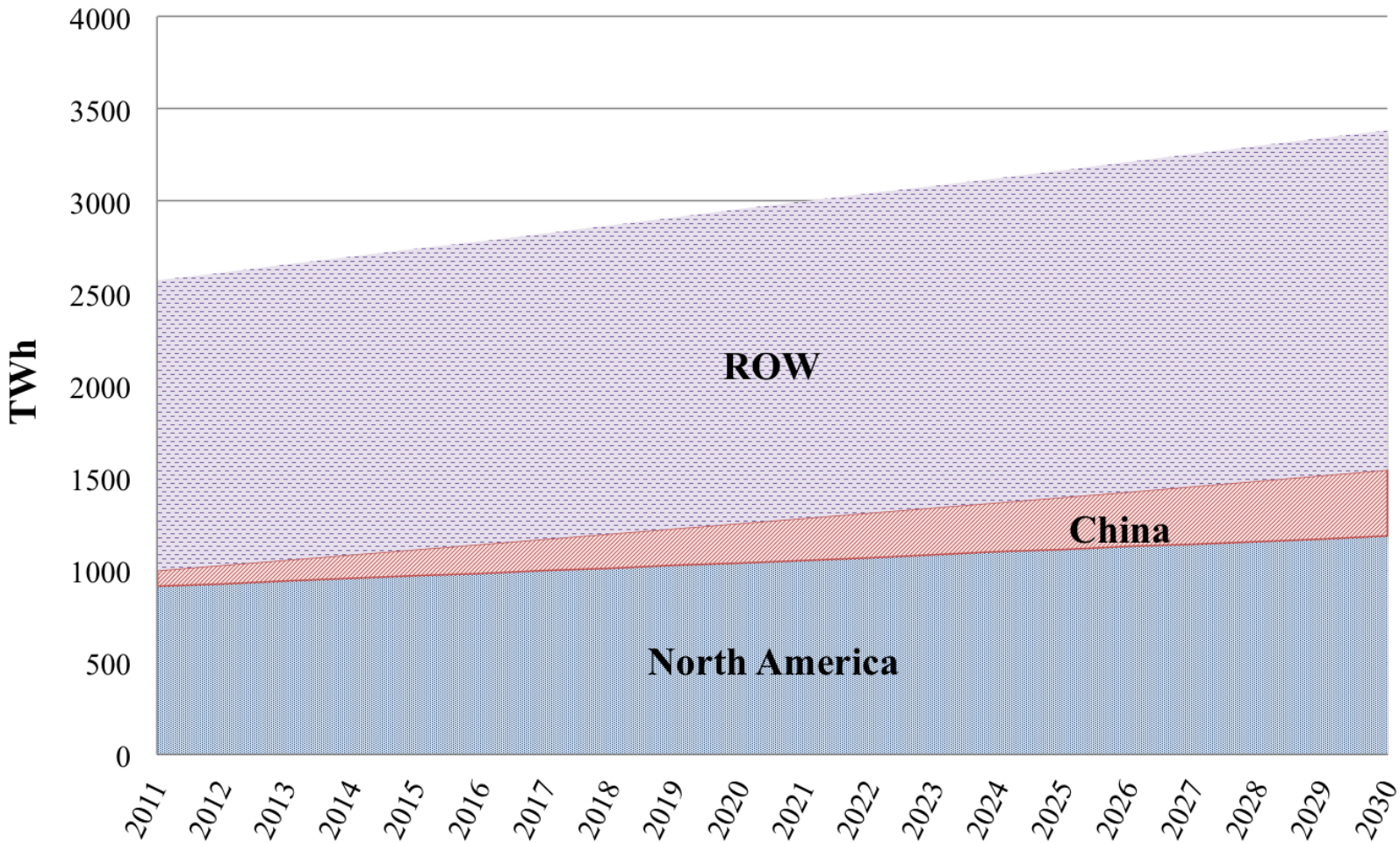


Aggregated over all countries (EIA, 2014)

Scenarios

- Moratorium on Nuclear Capacity: Assume zero growth in nuclear power from 2011 to 2030 at 380 GWe
- Planned Nuclear Growth: 767 GWe by 2040 (IEA, 2014)

Planned Nuclear Growth



IEA (2014)

Planned Nuclear: Regional Targets

	Nuclear Generation (TWh)	
	2011	Planned Nuclear, 2040
North America	911	1,183
China	86	1,029
ROW	1,571	2,205
World	2,568	4,417

Calculations based on IEA (2014) projections.

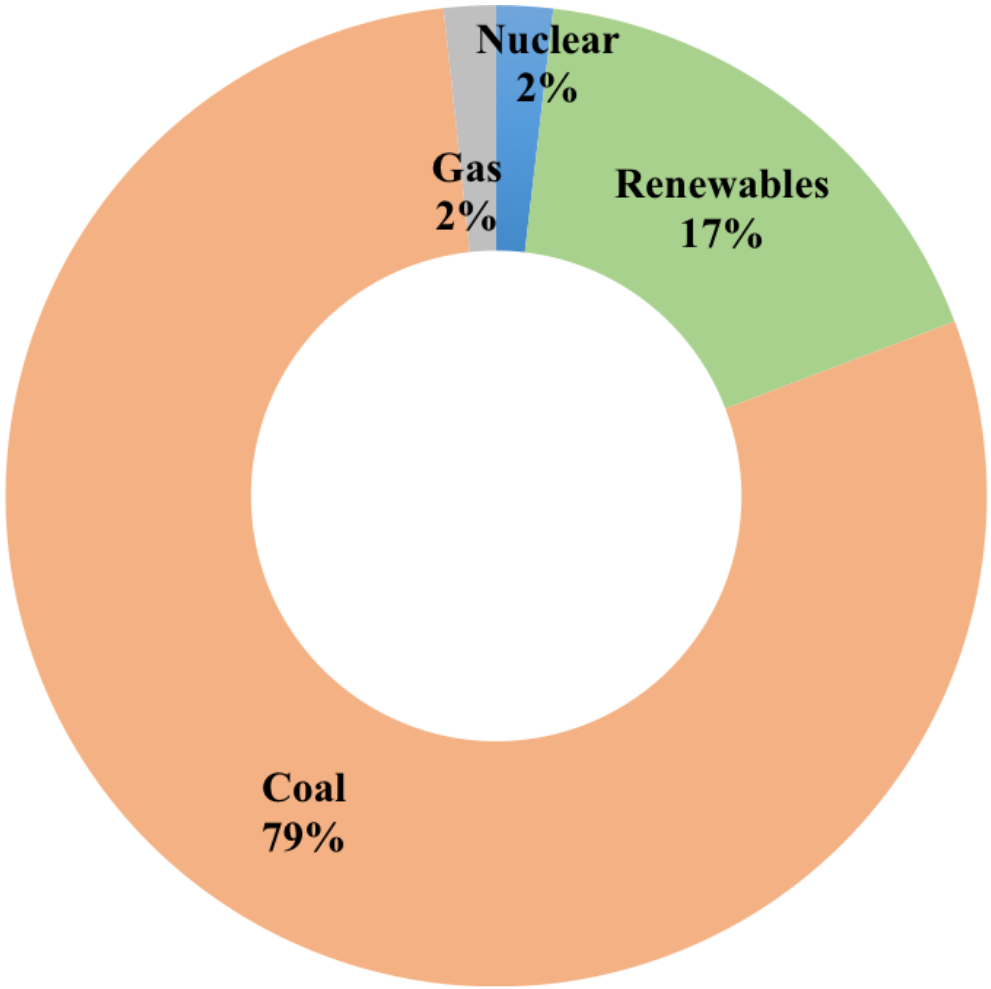
Carbon Taxes and Nuclear Growth

- We impose an annual carbon emissions target
- How did we define this target?
    - Carbon tax with nuclear growth: a tax of \$50 per ton (constant 2005) of CO_2 is imposed in each region
    - The annual amount of global carbon emissions from this scenario is defined as the *Global Emissions Target*

Carbon Taxes and Nuclear Growth

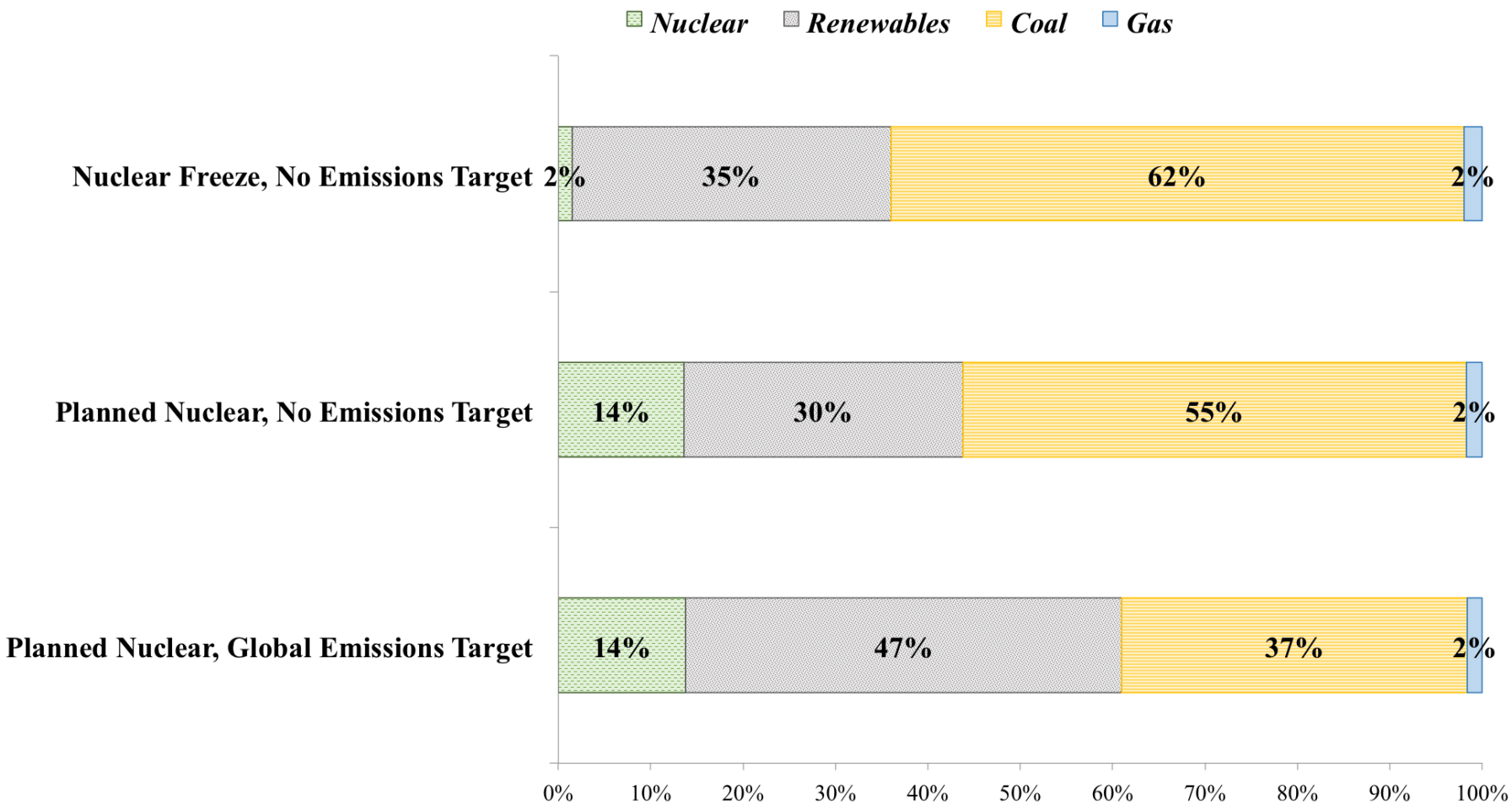
Annual Carbon Emissions in Billion Tons of CO_2 in 2030			
	Planned Nuclear without Carbon Tax	*Planned Nuclear with Carbon Tax*	*Emissions Reduction*
North America	6,726	5,819	−15%
China	12,099	9,668	−22%
ROW	20,968	17,054	−20%

Electricity Output by Fuel (2011): China

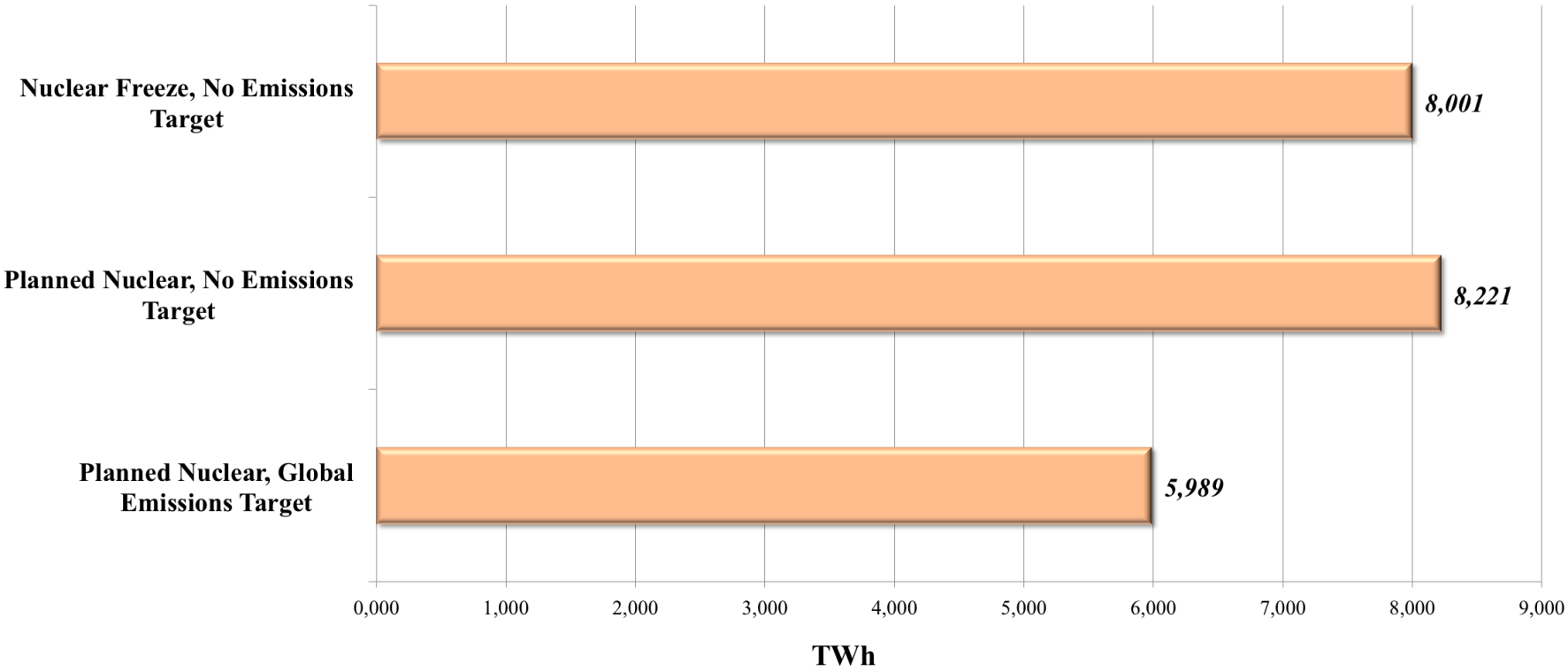


Output ***4,534 TWh***

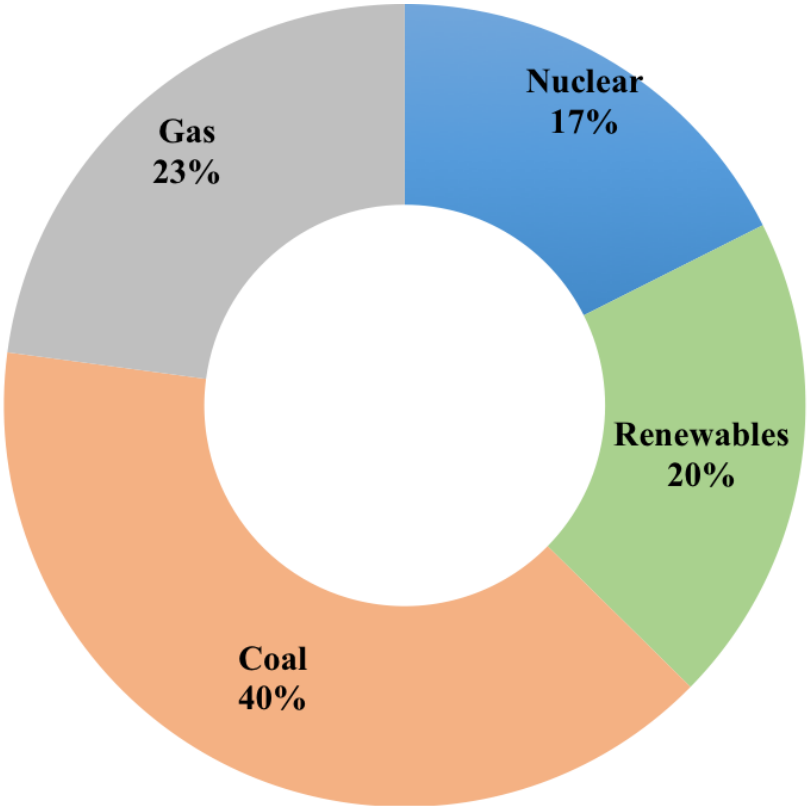
Electricity Output by Fuel (2030): China



Electricity Output in TWh (2030): China

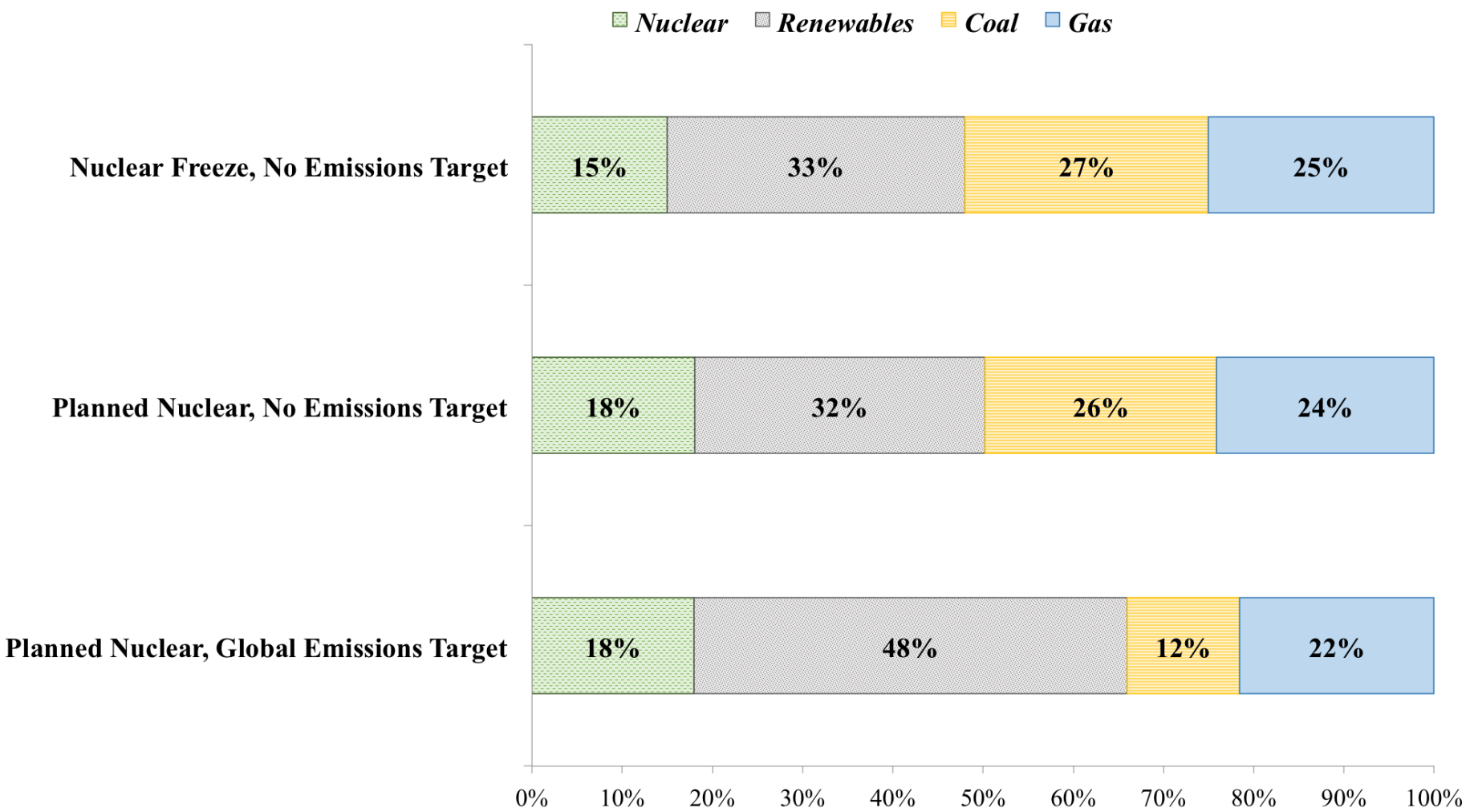


Electricity Output by Fuel (2011): North America

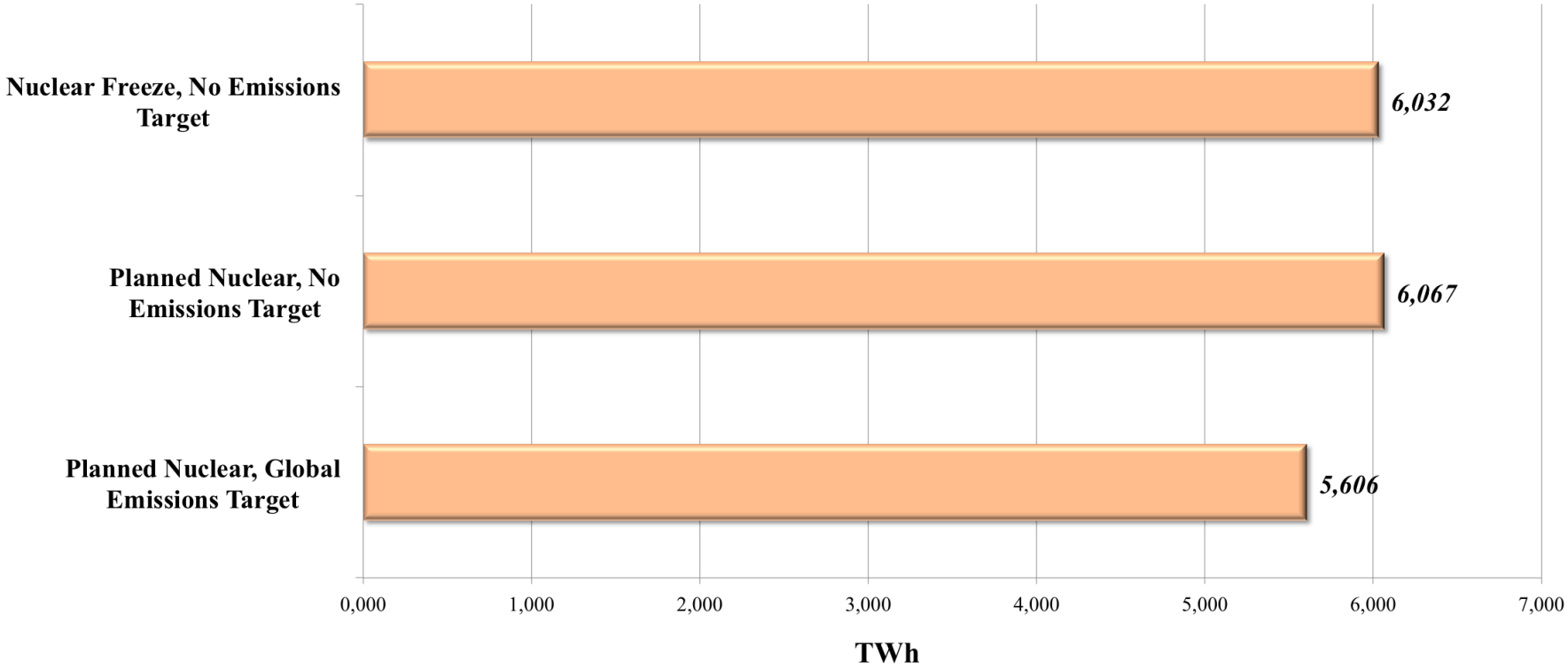


Output ***5,182 TWh***

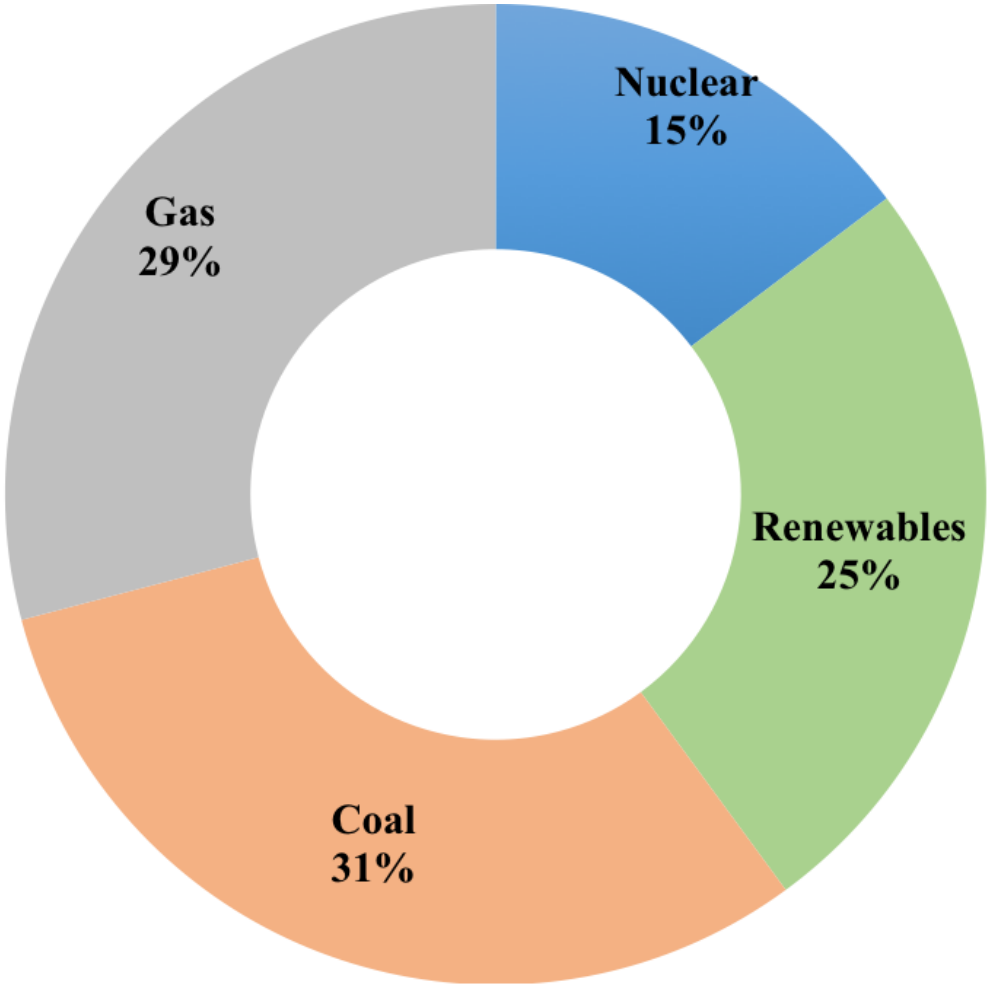
Electricity Output by Fuel (2030): North America



Electricity Output in TWh (2030): North America

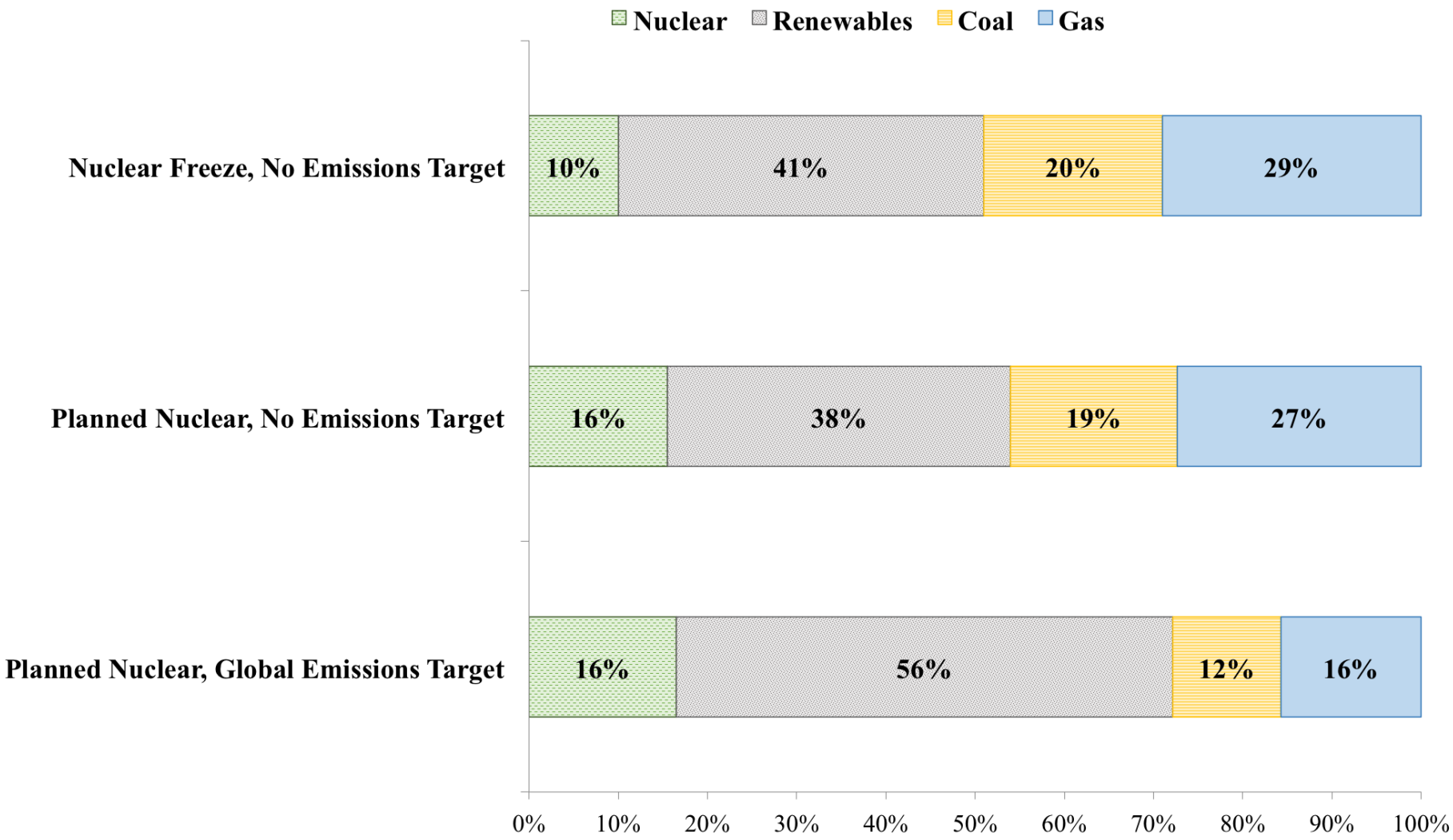


Electricity Output by Fuel (2011): ROW

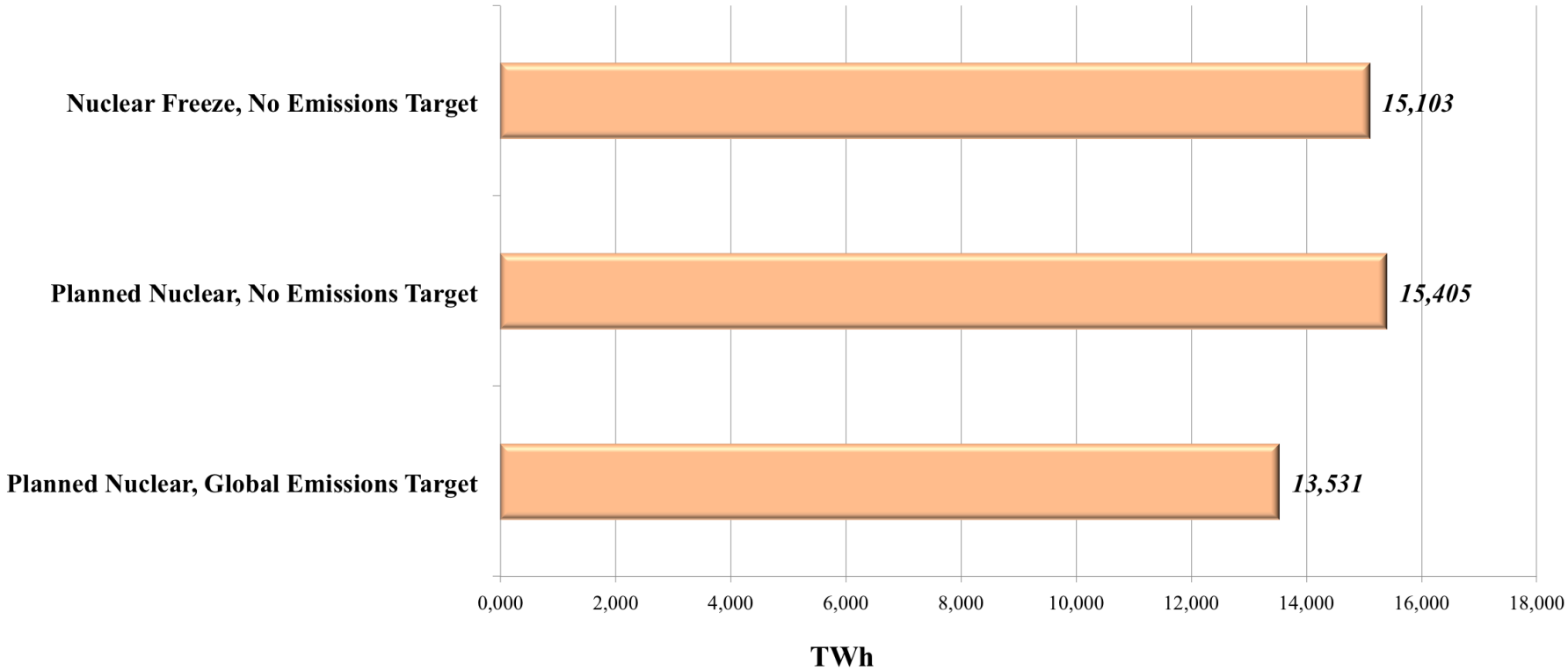


*Output **11,150 TWh***

Electricity Output by Fuel (2030): ROW



Electricity Output in TWh (2030): ROW



The Implicit Carbon Tax

- In the scenario, *Global Emissions Target* the carbon tax is USD 50 dollars per ton of CO_2
- Global carbon emissions decrease by 18% compared to the scenario without carbon tax

Main Results

- Big reductions in Coal use but only with Carbon Tax
- Nuclear Alone Does not Deliver
- Renewables Occupy Large Share
- Gas Share does not Budge, at least not in China
- Big Impacts are in China and ROW, Not in North America

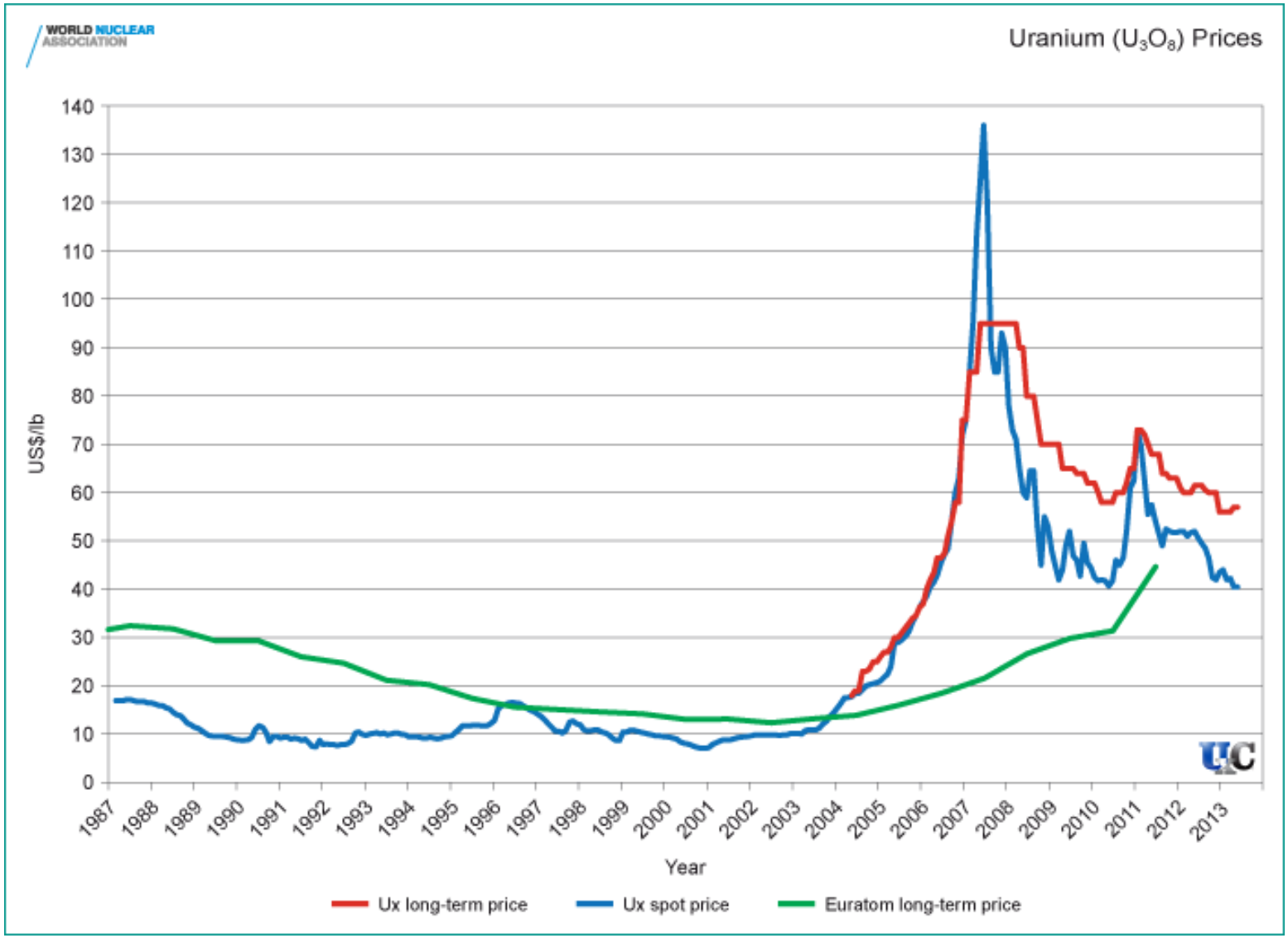
Future Work

- Need Cost Estimates of Tax and Pro-Nuclear Policies
- Are Large Shares of Renewables Realistic? Which Renewable? Some have Problems
- Need to Disaggregate in Model

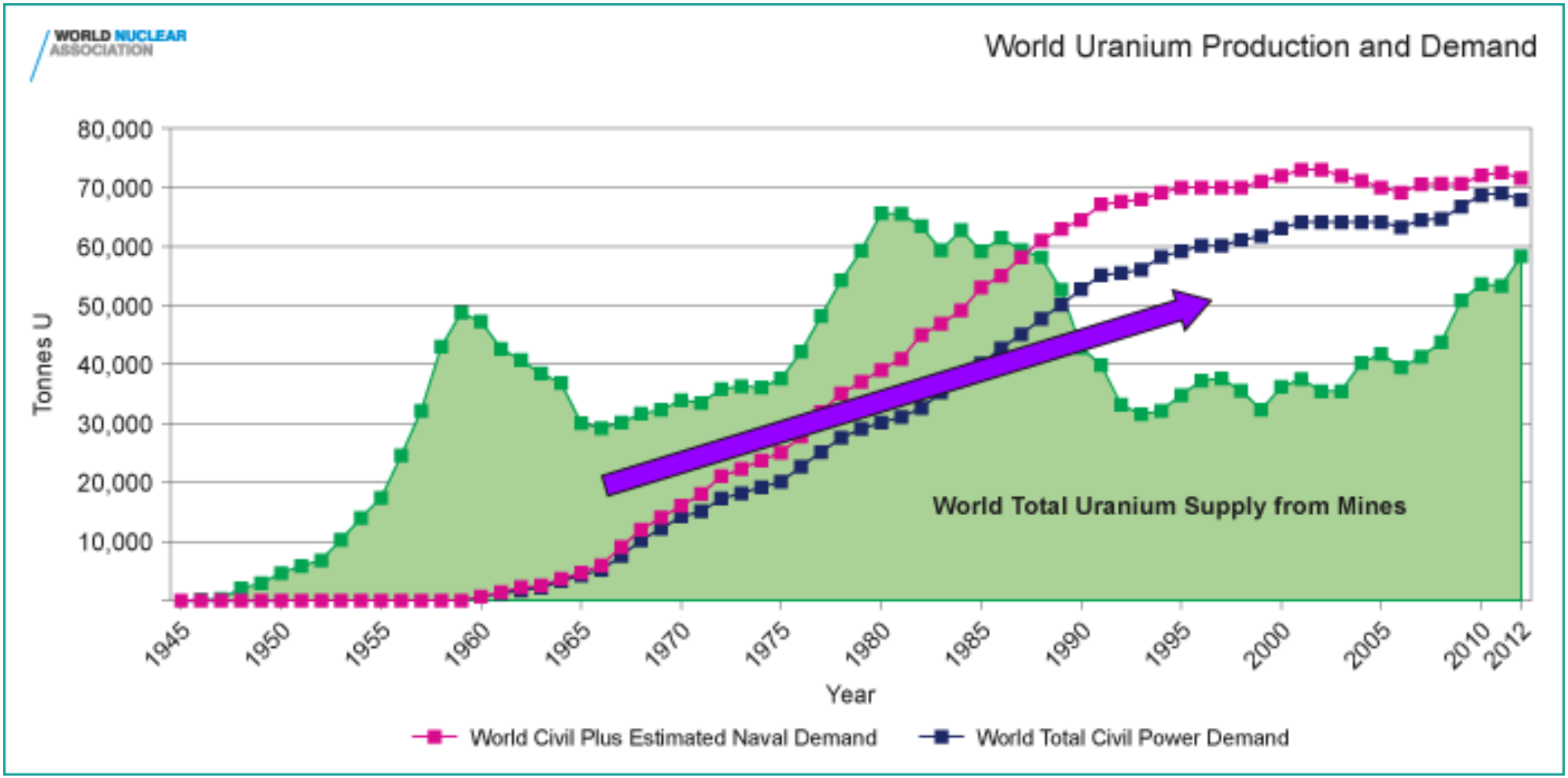
Further Extensions

- Break down ROW especially EU; Russia and India, both have aggressive nuclear programs
- How many Old Plants will be replaced?
- Learning in Nuclear Design and Efficiency relative to Learning in Other Technologies
- Our previous estimates suggest The Cost of Meeting Kyoto Type targets was cut in half by nuclear, may not hold today

Trends in Uranium Prices



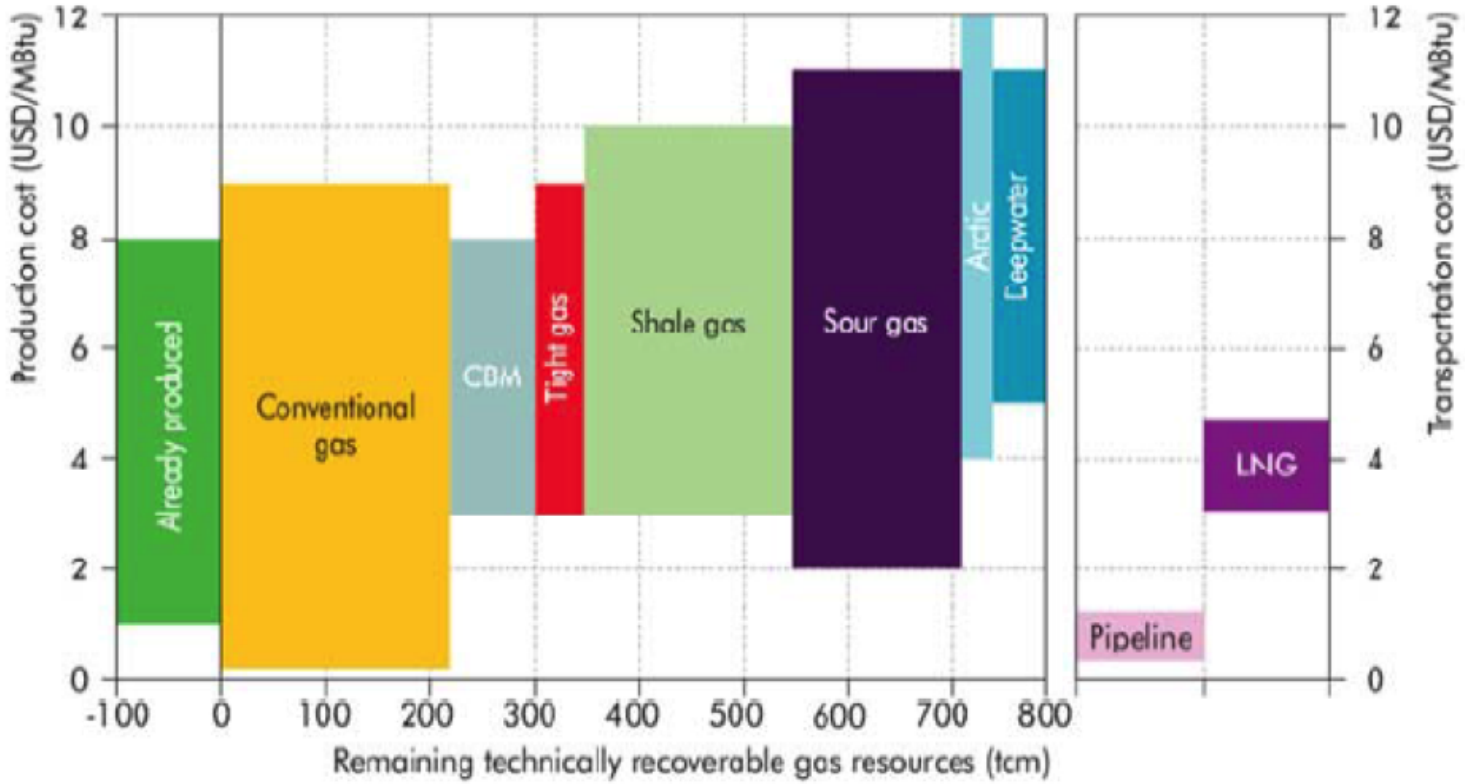
Uranium Supply and Demand



The Prognosis

- Nuclear Power will continue as a Major Fuel for Electricity
- But It may not be the Panacea for solving the World's Clean Energy Problem

Long Run Supply Curve for Natural Gas



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