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"IMPACT OF SMALL MODULAR REACTORS IN A CARBON CONSTRAINED ECONOMY"

THE NEED FOR REAL SOLUTIONS

The United States faces a major energy supply problem with two main consequences:

- 85% of the energy consumed emits CO_2.[1] National Academy of Sciences indicates greenhouse gases are detrimental to our environment and pose a problem that must be solved now.[2]
- 17% of the nation's energy comes from imported oil.[1] The vulnerability of our energy supply exposes it to price controls from OPEC, and to the whims of Iran who controls a 33 km wide strait. In other words, Iran can shut-off 30% of the world's oil supply overnight.

Possible Federal legislation taxing CO_2 through cap-and-trade provides an economic incentive to minimize greenhouse gas emissions.[2] When coupled with nuclear technology, the tax provides the necessary incentive to reallocate domestic energy reserves and eliminate imported oil.

THE IMPACT OF THE AMERICAN POWER ACT - COAL TO DISPLACE FOREIGN OIL?

- Using Light Water Reactors (LWR) to supply baseload power and Sodium Fast Reactors (SFR) to convert coal power plants to nuclear plants liberates coal from generating electricity. Once *freed*, coal is converted into natural gas supplying transportation fuel. Over time, the only sector adversely impacted will be the oil industry, which is mostly foreign supplied.
- Small Modular Reactors (SMR) – both fast and thermal – provide readily scalable energy sources. Their small size allows utilities to mitigate financial liability at equivalent prices to monolithic reactors. (Unless specifically noted, all costs are reported in constant 2008 dollars.)

UNIQUE MARKET OPPORTUNITY FOR NUCLEAR POWER

Competition for power conversion will intensify under cap-and-trade – look at how taxing CO_2 will impact various generation sources. Table I shows the pertinent financial assumptions and the resultant levelized costs of electricity under the American Power Act. SMR (fast and thermal) are the best choices for *baseload* power. Their total project costs are around $500 million compared to the $5 billion of large reactors like the AP-1000. If nuclear is to be widespread into the electrical grid (>40%), small utilities must be able to afford the technology. The cost of the large reactors is not a reasonable option for a utility with a market capitalization under about $10 billion. Thus financing is problematic for 70% of total generation.

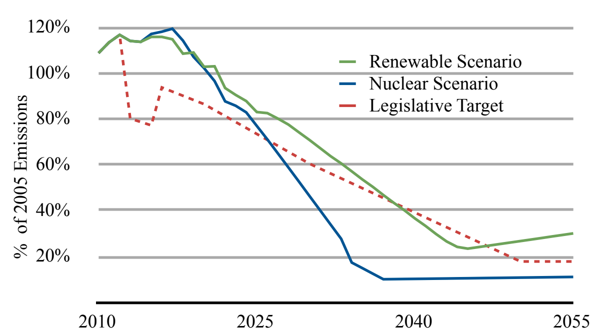

Fig. 1. High carbon tax scenario reductions in CO_2 emissions from 2005 levels

Because cap-and-trade makes coal generation with or without carbon capture cost prohibitive, nuclear power is the only cost effective, zero carbon source. LWR produce the most inexpensive source of *baseload* power, but with oxide fuel they are not flexible enough to be *load following*. Due to its resilience, metallic fuel allows nuclear to generate *intermediate loads*. When coupled with the SFR, this allows the direct replacement of fossil boilers. This preserves much of the utilities' existing capital investments in the Balance of Plant (BOP) and transmission lines.

Should a utility decide to produce methane from coal and process heat from the SFR, they also preserve the capital invested in the coal handing equipment, by continuing its use.

The International Atomic Energy Agency forecasts nuclear power demand doubling by 2030. This will stress the uranium supply chains and introduce significant cost uncertainty in the nuclear fuel cycle. By introducing the SFR and metallic fuel, utilities gain control of their fuel supply and secure an inexpensive and indefinite fuel source from existing "waste".

Renewable Energy Limits Economic Growth

Utilities are trying to figure out how to control costs and

- meet the proposed CO_2 targets
- minimize the cost impact to the customer
- minimize the amount of new construction
- continue the use of most of their existing assets

A model utility (based on a survey of several southeastern utilities) was created to assess Electrical Power Research Institute's (EPRI) best case of the 2009 PRISM/MERGE "Full Portfolio."[3,4] The model utility's market capitalization was $12 billion in 2010.

The model utility's "Renewable Portfolio" differed from the "Full Portfolio" with the use of nuclear power to generate all baseload power, and the absence of coal in long-term electric generation. EPRI attempted to maximize the use of coal assets and minimize nuclear construction, but failed to see that under cap-and-trade coal is no longer economical to produce electricity. EPRI did not look for other potential uses for coal, so long term energy prices are out of control in their scenario.

The EPA's analysis of the American Power Act made the same logical fallacy as EPRI, but had nuclear growth similar to the "Renewable Portfolio". To meet carbon targets the EPA requires a 22% reduction in energy consumption. Thus, limiting the size of the economy.

Nuclear Portfolio Enables Utility Growth

In the *Nuclear Portfolio,* the utility

- uses a combination of large reactors and SMR for baseload
- includes the conversion of coal plants to SFRs
- includes production of natural gas from coal

The Nuclear Portfolio also allows the utility to enter the transportation fuels industry and control costs.

Figure 2 shows the levelized cost of electricity including external costs and cost reductions from the sale of natural gas (~$10/MW-hr by 2050). Figure 5 shows the Nuclear Portfolio's generated electricity. The limited number of light water SMRs is due to the assumptions that a Construction Operation License (COL) is issued in 2022. If issued sooner, more SMRs will be built because of their economic advantage.

The utility was assumed to exist in a regulated

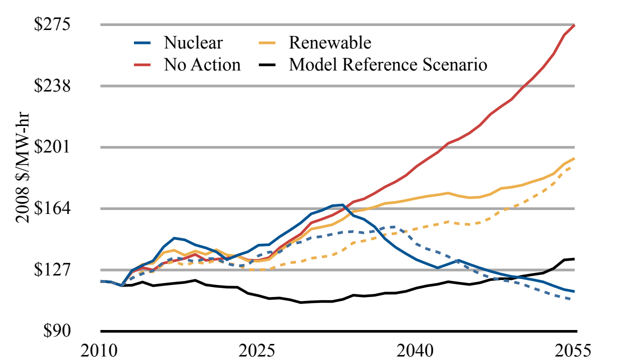

Fig. 2. Total levelized cost of electricity for each scenario including cost externalities. Solid lines are for the high carbon tax scenario and dashed lines are for the low carbon tax scenario. The reference scenario includes no carbon tax.

market. By using assets regulated by a Public Service Commission, extra profit from the sale of natural gas on the open market would also be regulated. Instead of passing the profit to the share holder, the profit is passed to the rate payer in the form of reduced electric costs. Lower energy prices helps attract more industry to the service area and promotes long-term growth.

A National "Energy Renaissance"

This country is struggling with exiting the recession, high unemployment, a perceived inability of Congress to legislate, fear of cap-and-trade legislation while the spill in the Gulf is putting more jobs at risk. Without changing our thinking about domestic energy policy, it all may continue.

Some might argue the "Nuclear Portfolio's" construction schedule of the SMRs and SFRs is not possible. If we follow conventional reactor construction models, they may be right.

This thinking ignores our nation's history. In World War II, Germany and Japan failed to realize the industrial potential of our nation and lost the war. The United States used innovative construction techniques, and produced 3 liberty ships a day with an average ship construction time of 42 days. We created a massive industrial complex to end the Great Depression and eliminate 17% unemployment. Who says the "Renaissance" only embraces nuclear power? It's also nation's avenue forward to gain positioning in the world's future.

More Benefits

The utility was scaled to the *entire generation capacity* of thenation to explore the macroeconomic impact that SMRand SFR will have under cap-and-trade.

Figure 3 shows the annual percent change in Gross Domestic Product (GDP) in consumption, investment and total GDP. The percent change in GDP is the amount above or below Energy Information Agency's (EIA) Annual Energy Outlook 2010.[5] Only transportation and utilities (~70% of total energy consumption) was examined. (The cost of carbon dioxide due to direct consumption of fossil fuels in residential and industrial applications was not included.)

When looking at Figure 3 a negative change in consumption may seem bad for the economy. In this case, it shows an overall decrease in the total economic cost of energy as a fraction of GDP. So, *negative* is cheaper energy and *positive* is more expensive energy. The change in imports/exports is included in the total GDP by equation (1).

(1) Total GDP = Consumption + Investment + Government Spending + Exports - Imports

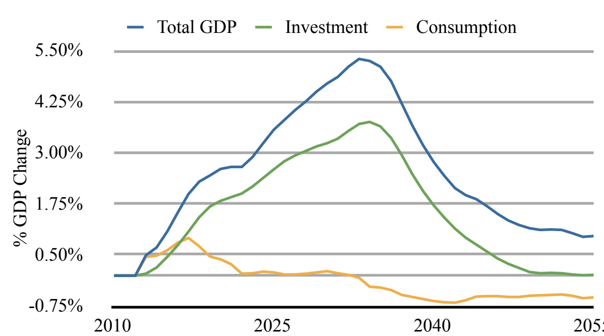

Fig. 3. The nuclear scenario's affect on GDP measured as change in % GDP from EIA

(The change in tax revenue was also examined, but not included in the GDP analysis.) An exogenous tax increase (raising taxes just to increase revenue) of 1% GDP can cause a 1.3-4.7% drop in GDP. Whereas an increase in tax revenue to reduce national debt does not have substantial output costs.[6] Thus interpreting the impact of the $920 billion in additional tax revenue by 2035 depends on how Congress appropriates it.

The revenue in Figure 4 comes from the additional money created by producing transportation fuel domestically and from nuclear power.

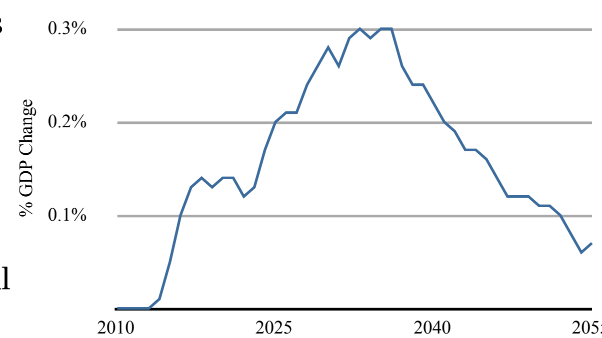

Fig. 4. The nuclear scenario change in tax revenue from EIA reference scenario as % GDP.

Rethinking Nuclear

- The problem our nation faces is an energy supply problem.
- The competition for nuclear power is not coal and natural gas.
- Under the carbon constraints of the American Power Act, there is no other competition with nuclear electric generation.
- Energy reserves – coal, natural gas, nuclear – exist domestically so the nation can become an exporter of fuels and technology instead of an importer.
- View cap-and-trade becomes a win-win opportunity for the all Utilities . . . to ensure low cost electrical energy, national security and cut CO_2 emissions.

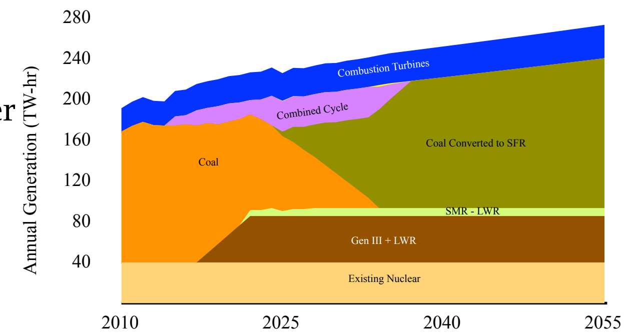

Fig. 5. Nuclear portfolio annual generation

TABLE A.I. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies

Technology	Online Year	Size (MW)	Lead Time (years)	Overnight Cost[b] (2008 $/kW)	Variable O&M (2008 $/ MW-hr)	Fixed O&M (2008 $/MW)	Incremental Capital Cost (2008 $/MW)	Thermal Efficiency	Capacity Factor	Busbar Cost[e,f] (2008 $/MW-hr)
Scrubbed Coal New	2013	600	4	2223	4.69	28150	17790	37.1%	76%	155
IGCC with carbon sequestration	2016	380	4	3776	4.54	47150	18038	31.6%	76%	143
Adv Gas/Oil Comb Cycle (CC)	2012	400	3	968	2.04	11960	7631	50.5%	76%	100
Adv CC with carbon sequestration	2016	400	3	1932	3.01	20350	12043	39.6%	76%	116
Adv Comb Turbine	2011	230	2	648	3.24	10770	2891	36.7%	30%	148
AP 1000 (Gen III+)	2016	1154	6	3820	0.18	64000	25545	32.5%	90%	97
mPower (Gen III++)	2022	125	4	4011	0.18	57600	11005	30.0%	90%	91
S-PRISM, New (Gen IV)	2025	622	4	5214	0.20	68000	23493	38.0%	76%	137
S-PRISM, Converted Coal (Gen IV)[g]	2025	311	4	4014	0.22	74800	17107	33.5%	76%	108
Wind	2012	50	3	1966	0.00	30980	7455	34.5%	34%	158
Wind Offshore	2013	100	4	3937	0.00	86920	16736	34.5%	39%	282

a - Online year represents the first year that a new unit could be completed, given an order date of 2009.

b - Overnight capital cost including contingency factors, excluding regional multipliers and learning effects. Interest charges and transmission investments are also excluded. These represent costs of new projects initiated in 2009.

c - O&M = Operations and maintenance.

d - For wind technologies, the thermal efficiency shown represents the average efficiency for conventional thermal generation as of 2008. This is used for purposes of calculating primary energy consumption displaced for these resources, and does not imply an estimate of their actual energy conversion efficiency.

e - Tax incentives are not included in the analysis reflecting nth of a kind costs after tax incentives for technological deployment expire.

f - Includes transmission investments, and carbon dioxide charges from the American Power Act high CO_2 tax for all fossil fuels.

g- Coal Converted to SFR overnight cost is the overnight cost of a new construction SFR minus $1,000/kW.

Sources: The model was based on and benchmarked against the Congressional Budget Office.[7] The values shown in this table are derived from Energy Information Agency, Idaho National Laboratory, conversations with vendors, and the Congressional Budget Office.[5,7,8,9]

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Introduction to Cal Abel

He graduated from the University of Wisconsin-Madison with a Masters in Nuclear Engineering, served ten-years in the Nuclear Navy first as a junior officer, then as an instructor at a nuclear prototype in Charleston, SC. In his final tour, he was the Engineering Officer on the guided missile submarine, USS Florida. He is now enrolled at Georgia Tech in their Nuclear Engineering doctoral program studying the role small reactors can have in the economy and the policy implications.

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