Discussion Paper for DOE SEAB/SMR Subcommittee

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Small Modular Reactors and U.S. Clean Energy Sources for Electricity

In his 2011 State of the Union speech President Obama stated: "By 2035, 80 percent of America's electricity will come from clean energy sources." As yet, there is no official definition of a clean energy source, but a sensible definition is to suggest a "clean energy standard" where sources are weighted with respect to how much CO_2 they emit per unit of electrical energy produced. That is:

Where

$\boldsymbol{F_{CE}}$ = Fraction of electricity for clean energy sources (multiply by 100 to get percent)

$\boldsymbol{\varphi_i}$ = CO2 Weighting factor; CO2 emitted per electricity supplied from source(i), relative to coal (0 to 1)

$\boldsymbol{E_i}$ = Electricity supplied from source (i)

$\boldsymbol{E}$ = Total electricity supplied

From the Energy Information Administration's (EIA)[1]:

Source	Coal	Gas	Nuclear	Hydro	Renew	Petrol	Total
Electric (TWhr)	1800	785	800	250	130	40	**3805**
%	47.4	20.7	21.1	6.6	3.4	1.1	**100**
CO_2 Emit (GT)	1.85	0.4	0	0	0	0.04	**2.3**

Table 1. Current U.S. Electricity Supply Distribution

Coal and Petroleum sources emit 1 Ton of CO2 for each MWhr of electrical energy produced, and natural gas emits ½ ton so $\boldsymbol{\varphi}$ for coal is 1 (by definition) and $\boldsymbol{\varphi}$ for petroleum is 1, and $\boldsymbol{\varphi}$ for natural gas is 0.5. Thus the current mix of electricity generated in the U.S has a "clean energy standard" of:

F_{CE} = 1-[[(1800 +40) + (785 X 0.5)]/3805] = 0.42 or 42%.

The EIA projects the electricity supply distribution in 2035 to be:[2]

[1] Energy Information Administration http://www.eia.doe.gov/mer/pdf/pages/sec7_6.pdf

[i]Source	Coal	Gas	Nuclear	Hydro	Renew	Petrol	Total
Electric (TWhr)	2100	1030	870	250	320	0	**4570**
%	46.0	22.5	19.0	5.5	7.0	0	**100**
CO_2 Emit (GT)	2.1	0.5	0	0	0	0	**2.6**

Table 2. EIA Projection of Electricity Supply Distribution in 2035

For this supply distribution, the fraction of electricity from clean energy sources in 2035 is:

F_{CE} = 1-[[(2100) + (1030 X0.5)]/4570] = 0.43 or 43%.

Thus EIA projects that the clean energy standard will essentially remain constant.

To get a sense of how the President's 80% Clean Energy goal can be used to set a goal for the deployment of SMRs we first must assume the contribution of the other sources, and then subtract what remains to be supplied by SMR.

Rounding off the amount of electricity demanded in 2035 to 4600 TWhr, [1-F_{CE} = 0.2], 0.2 X 4600 = 920 weighted TWhr are allocated to fossil fuels. Assume the nominal Administration's goals for Carbon Capture and Sequestration (CCS) for 2035 are 200 TWhr (~4% of U.S. electricity), and assume also that working high efficiency CCS plants have a CO2 weighting factor of 0.1. That leaves 900 (weighted) TWhr to be divided between coal and natural gas. If we take the natural gas figure to be 1200 TWhr, (600 weighted TWhr) that leaves 300 TWhrs for coal.

For the clean energy goal to be met, then, the non-carbon emitting sources must provide some 2900 TWhr. Hydropower is generally assumed to have reached a maximum of 250 TWhr, so if we assume renewables reach 650 TWhr, (double the EIA estimate) that leaves 2000 TWhr for nuclear power. If the Administration's loan guarantee program for current large reactors is successful, then one might expect the large reactors to reach 1000 TWhr by 2035. This leaves some 1000 TWhr for SMR – that is a lot of electricity. This distribution is summarized in Table 3.

Source	Coal	Coal (CCS)	Gas	Nuke (large)	Nuke SMR	Hydro	Renew	Total
Electric (TWhr)	300	200	1200	1000	1000	250	650	**4600**
% Elect	6.5	4.4	26.1	21.7	21.7	5.4	14.1	**100**
CO_2 Emit (GT)	0.3	.02	0.6	0	0	0	0	0.92

[2] It is worth noting that the EIA projection for 2035 is proportional to the expected increase in U.S. population from 300 Million to 360 Million, so the per capita use of electricity in the U.S. is projected to remain constant at ~ 12,700 kWhr/year/person.

Table 3. Projected Electricity Supply to meet Administration Goal of 80% Clean Energy by 2035

At first blush, the possibility of adding 1000 TWhr of SMR to the U.S. electricity supply by 2035 would seem way-overly optimistic. Assuming a capacity factor of 0.9, this would mean an installed SMR capacity 130 GW(e). It is unlikely that any SMR factory could get up and running before 2025, so that to reach that capacity by 2035, the SMR industry must, on average, produce and start operating some 13 GW(e) per year. On the other hand, from an historical perspective (Figure 1) the prospect of adding around 10-15 GW/year of SMR does not look so outlandish. During the 1970's and 1980's nuclear additions of large (~GW) plants were not far off from this number, and indeed the fundamental concept of SMR is factory manufacture and on-site assembly so as to maximize potential rate of market entry.

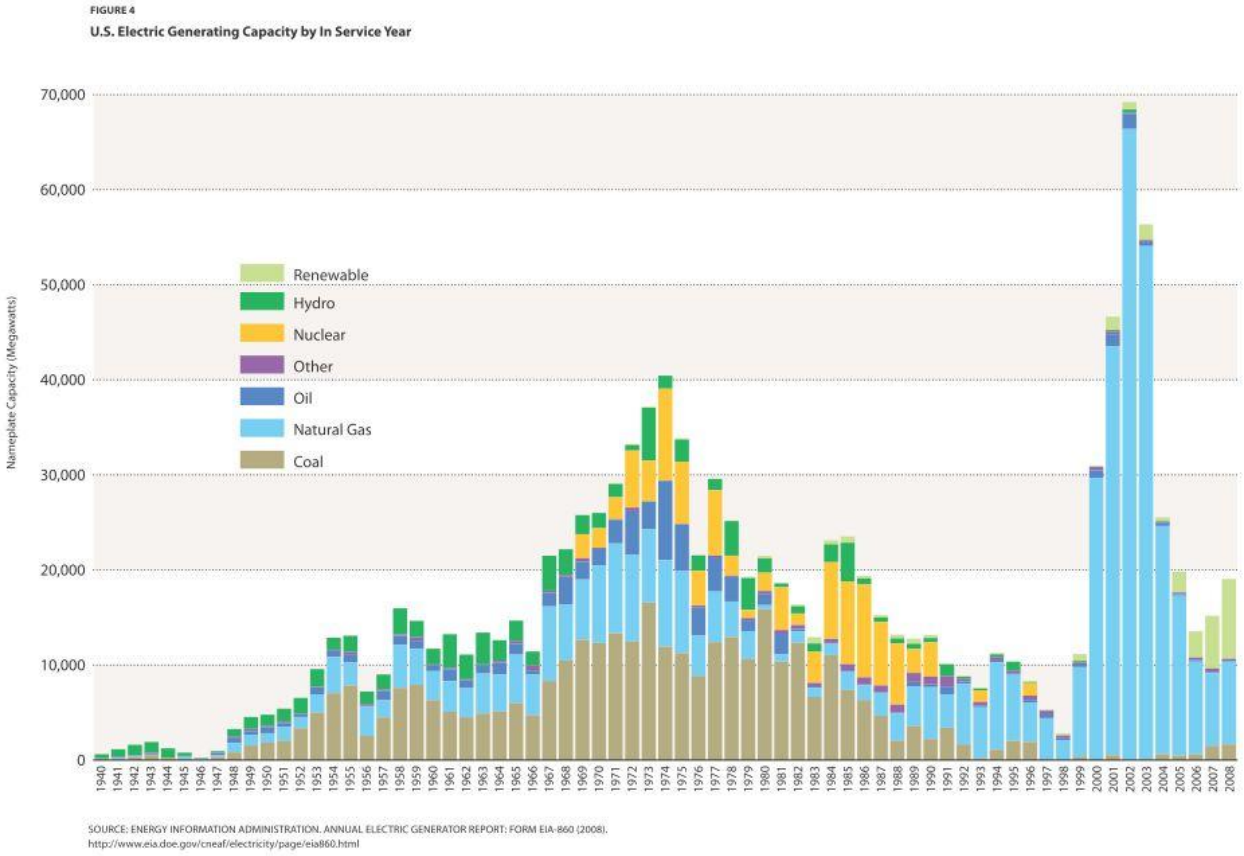

Figure 1. Annual Increase in U.S. Electricity Generating Capacity

Thus we may conclude:

1) If President Obama's goal of 80% of the 2035 U.S. electricity is to be supplied by "clean energy" sources, SMR must be a major contributor.
2) The rate of entry of SMRs into the U.S. supply inventory will be a serious industrial challenge.