APPENDIX 10-C. FULL FUEL CYCLE MULTIPLIERS

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APPENDIX 10-C. FULL FUEL CYCLE MULTIPLIERS

10-C.1 METHODOLOGY

To provide one unit of energy to the final consumer, for example, in buildings, vehicles or industrial processes, a variety of fuels are used in upstream activities. Thus, if the point-of-use (site) energy demand is reduced by one unit, the economy-wide demand for energy will be reduced by an additional amount corresponding to this upstream fuel use. The sum of site energy and upstream energy is called the full-fuel cycle (FFC) energy. This appendix provides a brief description of the methodology used to calculate FFC savings from the site energy savings that result from a candidate standard level. The mathematical approach is discussed in Coughlin (2012)[1], and details on the fuel production chain analysis are presented in[2] This appendix outlines the steps involved in the calculation, defines the data that are taken from the AEO and used in the calculation, and presents the results of the calculations for electricity, natural gas and fuel oil.

When all quantities are normalized to the same units, the FFC energy can be represented as the product of the site energy and an *FFC multiplier*. The multiplier is defined mathematically as a function of a set of parameters representing the energy intensity and material losses at each production stage. These parameters depend only on physical data, i.e. the calculations do not require any assumptions about prices or other economic data. Most generally, these parameter values may vary by geographic region, time, *etc*. For the calculations used in this analysis, the parameters represent national averages.

Schematically, the steps in the calculation of FFC energy associated with electricity savings are:

1. Assume the site energy savings, denoted S_0 (mWh), are known.
2. Site electricity savings are converted to electricity savings at the power plant, taking into account the transmission and distribution loss factors. The power plant electricity savings are given by $S_1 = tdloss*S_0$, where
   - S_1 is the power plant electricity savings (mWh)
   - *tdloss* is the transmission & distribution loss factor[a]
3. Power plant electricity savings are converted to fuel savings. This conversion depends on a set of parameters a_x where
   - x is an index used to indicate fuel type, with x=c for coal, x=g for natural gas, and x=p for petroleum fuels
   - a_x is the amount of fuel x consumed per MWh of electricity produced at the power plant
   - The fuel savings are $S_{2x} = a_x S_1$, for each fuel type x

[a] The values for *tdloss* are taken from NEMS. The value depends on region and changes slightly over the forecast period. The range of *tdloss* is 1.07 to 1.09.

The value of a_x over the analysis period is calculated from NEMS output. It depends on the capacity mix by fuel type, and on individual power plant efficiencies or heat rates, and so varies with region and with time. The higher the penetration of renewables, the lower the value of a_x.

4. For each fuel type x, an analysis of the fuel production chain determines the amount of energy required to produce one unit of fuel for site consumption. This analysis accounts for all energy sources, including electricity, that are used in fuel production. The consumption of fuel y required to provide one unit of fuel x for site consumption is denoted by the matrix element V_{xy}.
5. The matrix elements V_{xy}, which represent the incremental use of fuel y in the production chain for fuel x, are converted to the matrix elements M_{xy}, which represent the economy wide reduction in demand for fuel y resulting from a one unit reduction in demand for fuel x.
6. The equation $S_{3y} = \sum_x M_{xy} S_{2x}$ gives the full fuel cycle savings of fuel y.
7. The fuel savings are converted to energy units by multiplying S_{3y} by the heat content of fuel y, denoted q_y. The total FFC energy savings are given by the sum over the index y, so the total is equal to $\sum_x q_y S_{3y}$.

In addition to electricity, natural gas and petroleum-based fuels (primarily fuel oil) are used in buildings. The steps required to calculate the full fuel cycle energy use associated with production of gas or fuel oil are essentially identical to the scheme outlined above. The only difference is that the analysis begins at step 3, with the site fuel savings substituted for S_{2x}.

For simplicity in applications, the FFC energy use is summarized as a *multiplier* μ (mu). This is a dimensionless number that can be applied to the site energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (1-μ).

This methodology is completely general and is based on the mathematical definition of the quantity the FFC energy is meant to represent. The supporting numerical calculations of the parameters can be implemented in a variety of ways. As the data required are incomplete, some simplifying assumptions or approximations need to be made (these are explained in detail in[2]). These will generally have a limited quantitative impact, but may lead to small differences in the fuel cycle energy use parameters calculated by different authors. The GREET model developed by Argonne National Laboratory[3] is one example of a spreadsheet tool that calculates full fuel cycle energy use, with a focus on vehicle-fuel systems. For the Department's appliance standards energy savings estimates, the implementation of the FFC calculations has been designed specifically to make use of energy forecast data published in the AEO. These data include time series of:

1. Domestic production of natural gas by source type, imports of natural gas, and natural gas use by the oil and gas industry
2. Domestic production and imports of petroleum fuels by source type; total refinery inputs, outputs and refinery fuel use
3. Electric generating capacity by fuel type and fuel consumption for power generation
4. Coal use for power generation, by source type and coal quality

5. Fuel heat content for each fuel type

These quantities vary with each year in the AEO forecast period, leading to a corresponding variation in estimates of the full fuel cycle energy multipliers. Multipliers are presented in Table 1 for the AEO forecast years 2012 to 2035. To extend the analysis period beyond 2035, the years 2020 to 2035 are used to define a linear trend, which is then extrapolated to the final year of the analysis period.

For electricity, the site-to-source conversion factors are not included in the multiplier shown in Table 10-C.1.1. Hence, this multiplier is applied to the source energy savings. Site-to-source conversion factors are given in chapter 10.

Table 10-C.1.1 Full Fuel Cycle Multipliers for the AEO2011 Forecast Period

Forecast year	Source Energy Savings For Electricity	Site Fuel Oil Savings	Site Natural Gas Savings
2008	1.056	1.123	1.135
2009	1.058	1.120	1.129
2010	1.061	1.120	1.139
2011	1.060	1.118	1.139
2012	1.060	1.131	1.136
2013	1.059	1.130	1.133
2014	1.059	1.130	1.131
2015	1.059	1.129	1.129
2016	1.058	1.129	1.128
2017	1.058	1.130	1.127
2018	1.057	1.129	1.126
2019	1.057	1.128	1.125
2020	1.056	1.127	1.126
2021	1.055	1.127	1.125
2022	1.055	1.127	1.125
2023	1.055	1.127	1.125
2024	1.054	1.127	1.124
2025	1.054	1.127	1.123
2026	1.053	1.127	1.123
2027	1.053	1.127	1.122
2028	1.054	1.128	1.122
2029	1.054	1.128	1.121
2030	1.055	1.130	1.121
2031	1.055	1.131	1.120
2032	1.055	1.131	1.120
2033	1.055	1.131	1.120
2034	1.055	1.132	1.121
2035 on	1.055	1.132	1.121

REFERENCES

[1] Coughlin, Katie. (2012a) “A Mathematical Analysis of Full Fuel Cycle Energy Use.” *Energy* 37(1), pp. 698–708. http://www.sciencedirect.com/science/article/pii/S0360544211006803.

[2] Coughlin, Katie. (2012b) "Calculation of Full Fuel Cycle Multipliers for Energy Use in Buildings". Lawrence Berkeley National Laboratory, July 2012.

[3] Argonne National Laboratory. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. http://greet.es.anl.gov/