Generally, a temperature under reducing conditions should be equal to or lower than the corresponding temperature under oxidizing conditions. The difference in these temperatures typically increases with increasing iron content in the ash.

Three empirical equations correlating ash fusibility under reducing atmosphere against ash compositions were reviewed.

- Sondreal and Ellman (1975) - Softening temperature (ST) versus ash composition
- Bryers and Taylor (1976) - Hemispherical fusion temperature (HT) versus ash composition
- Winegartner and Rhodes (1975) - Initial deformation temperature (IT), ST, HT, Fluid temperature (AFFT), and AFFT-IT difference (Delta AFFT/IT) versus ash composition.

Of the above three, only the Winegartner and Rhodes (WR) correlation predicts AFFT based on ash compositions. In addition, the WR offers two different ways to estimate AFFT, 1) direct WR ($AFFT_1$) calculates AFFT as a function of ash composition and 2) indirect WR ($AFFT_2$) calculates AFFT as IT + Delta AFFT/IT, with IT and Delta AFFT/IT being functions of ash composition. The review uses the two WR correlations for predicting ash AFFT based on ash compositions.

The general formats of the WR equations are:

1. $AFFT_1 = C_{AFFT} + \Sigma\, ai_{(AFFT)} * xi$, °F

and

2. $AFFT_2 = (IT) + (Delta\ AFFT/IT) = (C_{IT} + \Sigma\, ai_{(IT)} * xi) + (C_{Delta} + \Sigma\, ai_{(Delta)} * xi)$, °F

Where C_{AFFT}, C_{IT} , C_{Delta}, $ai_{(AFFT)}$, $ai_{(IT)}$ and $ai_{(Delta)}$ are constants with xi being mole% i-th ash components defined by the WR correlations. The WR correlations and the associated constants and variables are those defined in the "Coal Conversion Systems Technical Data Book", prepared by Institute of Gas Technology (now the Gas Technology Institute, or GTI) for the U.S. Department of Energy.

2.1.2.1 Coal Ash Fusion Data

In order to test the ash fusion estimating methodology, actual data from laboratory measurements using accepted ASTM procedures are required. The following sources of ash compositions and ash fusion temperatures data are used for this study.

Coals from Pennsylvania counties as listed under the "Elemental Composition and Fusibility of Ash of Large Deposits of US Coals" section in DOE's "Coal Conversion Systems Technical Data Book". Only samples with both ash compositions and measured fusion temperatures are used. A total of 60 data points are available.

Coal samples from Nexant's in-house databank that contain both ash compositions and measured ash fusion temperatures. A total of 30 data points, including both domestic and foreign coals, are available.

Data for potential EECP feedstocks such as anthracite culms, Pittsburgh bituminous coal, petroleum cokes, limestone and other flux materials supplied by WMPI. Properties of these potential blending feedstocks are summarized in Tables 2-1 and 2-2.

Table 2-1
Potential EECP Feedstocks
WMPI Data

Description & Cases	Anthracite Culm Tailings			Bituminous Coal	Bituminous Coal	Coke Fluid	Petroleum Coke
	Design Case	Alternate Case 1	Alternate Case 1				
Feedstock Sample ID	A3	2A	A8	Hawk Mtn	Warner	Koch	P1
Proximate Analysis, wt%:							
Moisture	1.92	11.96	1.86	9.60	5.47	11.67	0.36
Volatile Matter	7.21	5.72	10.69	20.05	21.23	6.20	11.90
Fixed Carbon	71.25	64.72	67.83	52.27	54.88	81.48	85.95
Ash	19.62	17.61	19.63	18.08	18.42	0.65	1.79
Ultimate Analysis, wt% dry:							
Carbon	72.54	74.48	69.27	66.71	68.55	88.56	85.93
Hydrogen	2.32	2.30	3.46	4.15	4.13	1.80	3.90
Nitrogen	0.87	0.87	1.18	1.12	1.15	1.71	1.27
Sulfur	0.38	0.27	0.25	3.29	4.86	6.18	5.37
Chloride	---	---	---	---	---	---	---
Oxygen	3.89	2.09	5.84	4.73	1.82	1.01	1.73
Ash	20.00	20.00	20.00	20.00	19.49	0.74	1.80
HHV, Btu/lb(dry basis)	11,119	11,942	11,269	11,843	12,439	14,191	15,251
Ash Analysis, wt%:							
Silica, SiO_2	57.10	54.30	53.00	52.54	35.15	18.20	59.40
Aluminum Oxide, Al_2O_3	28.20	26.00	26.70	25.47	24.80	6.20	10.90
Iron Oxide, Fe_2O_3	5.69	4.95	8.41	14.80	29.39	4.10	12.10
Calcium Oxide, CaO	0.50	0.10	0.50	0.47	3.72	4.17	4.10
Magnesium Oxide, MgO	0.20	0.61	0.13	0.16	0.30	2.03	1.78
Sodium Oxide, Na_2O	0.62	0.91	0.37	0.16	0.42	1.52	1.56
Potassium Oxide, K_2O	2.97	2.45	2.77	2.06	1.72	0.49	1.21
Titanium Oxide, TiO_2	2.43	1.86	1.86	1.52	1.27	0.19	1.71
Nickel Oxide, NiO	---	---	---	---	---	2.25	---
Vanadium Pent-oxide, V_2O_5	---	---	---	---	---	47.17	---
Phosphorus Pent-oxide, P_2O_5	---	---	---	---	0.34	1.60	---
Sulfur Trioxide, SO_3	2.29	4.10	0.02	2.82	1.68	10.68	2.08
Others	---	4.72	6.24	---	1.21	1.40	5.16
Ash Fusion Temp in Reduced Atmosphere (ASTM D-1857), ^{o}F:							
Initial Deformation	2,740	2,450	2,269	2,490	1,949	> 2,700	2,131
Softening	2,790	2,475	2,688	2,535	2,090	> 2,701	2,489
Fluid	> 2,800	2,667	> 2,800	2,633	2,265	> 2,702	2,697

Table 2-2
Potential Flux Properties

Analysis Data	Description and Source Limestone Meckley	Iron Oxide Hawk Mtn	CFB Fly Ash WMPI
Proximate Analysis, wt%			
Moisture	---	10.56	---
Volatile Matter	36.84	27.64	9.30
Fixed Carbon	---	---	---
Ash	63.16	61.8	90.70
Ultimate Analysis, wt% dry			
Carbon	10.04	8.43	2.54
Hydrogen	---	---	---
Nitrogen	---	---	---
Sulfur	---	---	---
Chloride	---	---	---
Oxygen	26.80	22.47	6.76
Ash	63.16	69.1	90.70
HHV, Btu/lb(dry basis)	0	0	0
Ash Analysis, wt%			
Silica, SiO_2	15.40	3.96	55.70
Aluminum Oxide, Al_2O_3	4.95	2.12	25.80
Iron Oxide, Fe_2O_3	3.10	15.90	7.15
Calcium Oxide, CaO	71.80	46.30	---
Magnesium Oxide, MgO	1.80	7.68	0.15
Sodium Oxide, Na_2O	0.61	0.20	0.68
Potassium Oxide, K_2O	0.84	0.04	2.62
Titanium Oxide, TiO_2	0.25	0.14	2.29
Phosphorus Pentoxide, P_2O_5	---	---	---
Sulfur Trioxide, SO_3	1.20	0.65	---
Others	0.05	23.01	5.61

Data was provided by WMPI for two laboratory synthesized blends, with one being 95% anthracite culm with 5% limestone, and the second 95% anthracite culm with 2.5% limestone plus 2.5% Circulating Fluidized-Bed Boiler (CFB) fly ash. The measured ash fusion temperatures for the WMPI blends are listed below in Table 2-3.