Technical Memorandum

To: *City of Franklin*

From: *CDM Smith*

Date: *January 29, 2015*

Subject: *Franklin WRF Modifications & Expansion Project*
Results of THP System Supplier Pre-selection Evaluation

Introduction & Project Background

CDM Smith Inc. (CDM Smith) has been retained by the City of Franklin (the City) to design a new thermal hydrolysis pretreatment (THP) system for the Franklin Water Reclamation Facility (WRF). Since the available commercial THP systems on the market are substantially different, the City and CDM Smith agreed that the system supplier should be preselected prior to final design. It was agreed that the pre-selection evaluation would consider economic and non-economic criteria as outlined below. This technical memorandum (TM) documents the pre-selection evaluation process and the recommended THP system for the Franklin WRF.

Request for Proposal

The design criteria summarized in **Table 1** were used to develop a pre-selection package. The pre-selection package included a Thermal Hydrolysis specification, which described the scope of supply, performance requirements, and basis of design criteria. The package also included other equipment specifications that the Thermal Hydrolysis specification referenced in order to set a minimum standard of quality. Front end specifications were added to the package to outline the terms and conditions that the selected THP system supplier would be required to follow; the intent of these terms and conditions is to protect the City and the Contractor from construction issues that can arise for the Contractor in trying to manage the pre-selected vendor (i.e., the Contractor has very little leverage to negotiate changes to the pre-established agreement with a pre-selected vendor). These terms and conditions included, but were not limited to: measurement and payment, schedule, Contractor negotiations, bonds, warranties and performance guarantees.

This performance specification package was distributed to the THP system suppliers as their primary source of information for developing a proposal. On September 19, 2014, CDM Smith issued the Request for Proposals (RFP), including the pre-selection package, to the following THP system suppliers.

- Cambi Inc., Malvern, Pennsylvania

- I. Kruger Inc., Cary, North Carolina

Appendix A includes the RFP and the four addenda CDM Smith issued in response to system supplier questions.

Table 1: New THP System Design Parameters for the Franklin WRF

Parameter	Value	
Pre-Treatment Parameter		
1 – Provide thermal hydrolysis pretreatment	Thermally Hydrolyze waste activated sludge (WAS) to meet maximum month solids loading.	
2 – Meet Class A pathogen reduction requirements	Treat maximum month solids loading, which include WAS and Fats, Oils, and Grease (FOG) to achieve Class A pathogen reduction criteria specified in US EPA CFR Part 503.	
WAS Loading Rates (dry solids pounds/day)	Average Annual Day	Average Day Maximum Month
Initial Startup (Year 2018)	20,173	26,225
Phase 1 (Year 2025)	26,897	34,966
Phase 2 (Year 2040)	43,.035	56,946
FOG Loading Rates (dry solids pounds/day)	Average Annual Day	Average Day Maximum Month
Initial Startup (Year 2018)	677	1,001
Phase 1 (Year 2025)	801	1,201
Phase 2 (Year 2040)	1,168	1,768

Scope of Supply	
Solids Upstream End	
Contractor Supplied	Solids Chutes to Pre-Dewatered Sludge Storage Bins
THP System Supplier	Pre-Dewatered Sludge Storage Bins
FOG Upstream End	
Contractor Supplied	FOG piped to pulper or pasteurization tank
THP System Supplier	Equipment to treat the FOG to meet Class A
THP System Heating	
Contractor Supplied	Saturated Steam piped at pressure and flow required by the THP system
THP System Supplier	Steam feed control to the desired application point
THP System Cooling/Dilution	
Contractor Supplied	Plant Re-use Water Piped to THP cooling & dilution water equipment
THP System Supplier	Complete cooling system including pumps/control valves/heat exchangers, etc. to cool and dilute the sludge to appropriate temperatures for anaerobic digestion in the downstream mesophilic digesters.
THP System Power	
Contractor Supplied	480 Volt power to THP control panels
THP System Supplier	Control panels for each piece of equipment with motor starters and VFDs.
THP System Controls	
Contractor Supplied	Plant SCADA to communicate with the THP System PLC.
THP System Supplier	Complete PLC with HMI panels to operate the entire THP system.
FOG Downstream End (Kruger Only)	
THP System Supplier	Pumps to convey pasteurized/hydrolyzed FOG to the digesters.
Contractor Supplied	Pump discharge piping to convey pasteurized/hydrolyzed FOG to the digesters.
Solids Downstream End	
THP System Supplier	Pumps to convey hydrolyzed, cooled sludge to the digesters.
Contractor Supplied	Pump discharge piping to convey hydrolyzed sludge to the digesters.
Redundancy	
Pumps, Compressors, Other Mechanical Equipment	100% standby
Electrical	Dedicated Control Panel (one for duty and one for standby equipment)
Performance Guarantees (PG)	
Steam Demand	Steam Consumption as a function of solids loading
Percent Volatile Solids Reduction (%VSR)	%VSR in the digesters as a function of solids loading

The original submittal deadline for the proposals was October 6, 2014; that deadline was extended to October 24, 2014, and then again to October 31, 2014, in order to provide more time for the suppliers to respond. Both THP system suppliers returned proposals before the 5 p.m. Eastern Time deadline on October 31, 2014.

Using the information submitted by the THP system suppliers, CDM Smith evaluated the two proposed systems based on economic and non-economic factors that were developed with input from the City. Additional information needed to complete the evaluation was requested and obtained from each system supplier.

The major features of each system supplier's proposed system are summarized in **Table 2.** The complete proposals, including additional information submitted at CDM Smith's request, are attached to this TM as **Appendix B.**

Table 2: THP System Technical Comparison

Parameter	Cambi Inc. B-2 System	I. Kruger Inc. Exelys System
System Design		
Flow Type	Sequencing Batch	Continuous Plug
Required Steam Feed Pressure	160 psi	145 psi
Reactor Operating Temperature	165 degrees Celsius	165 degrees Celsius
Steam Demand @ 18% solids	350 lb/wet ton (WT)	588 lb/WT
Steam Injection	Lances inside Reactors	Inline Dynamic Mixer Upstream of Reactor
FOG Treatment Temperature	165 degrees Celsius (Integral to THP System)	75 degrees Celsius (Separate Pasteurization System)
Steam Recycling	Yes	No
Pressure Drop Cell Destruction	Yes	No
Containment for Reactor	No	Yes
System Configuration		
Sludge Storage Bin System	One bin with two 2hp vertical screws and two 3hp discharge screws,	One Bin with one 5hp leveling screw and two 10hp live bottom screws
Progressing Cavity Pumps	Two 15hp Pulper Feed Pumps Two 5hp Reactor Feed Pumps Two 5hp Digester Feed Pumps	Two 30hp THP Feed Pumps Two 20hp Pressure Holding Pumps
Inline Dynamic Mixers	None	Two 40hp steam/sludge dynamic mixers
Reactor(s)	Four batch at 2m^3 each	One Plug Flow at 7.5m^3
Additional Pressure Vessels	One Pulper and One Flash Tank, 4m^3 each	None
Heat Exchangers (HEX)	Three Cooling Tube in Tube HEX (two installed in Phase 1, and a third installed in Phase 2)	One Cooling Tube in Tube HEX One Gasketed Plate HEX
Water Service Pumps	Three 1hp Cooling Water Pumps (two installed in Phase 1, and a third installed in Phase 2)	Two 5hp dilution water pumps Two 20 HP Cooling Water Supply Pumps Two 20hp Cooling Water Circulation Pumps
Centrifugal Chopper Pumps	Three 5hp Digester Recirculation Pumps (two installed in Phase 1, and a third installed in Phase 2)	None
Air Compressors	Two 15hp air compressors	Two 15hp air compressors
Odor Control	Proprietary Process Gas Unit (PGU) 10hp PGU holds storage drum, two compressors and two pumps.	One 150 gallon Activated Carbon filter, submersible pump for expansion tank.
Valves	91 total, 6 safety, 60 manual, 25 pneumatically actuated.	65 total, (knife, ball, check, rupture disc), 17 of which are pneumatically actuated

FOG Pasteurization System	None	405 gallon tank with a 1hp mixer, One 5hp digester feed pump (rotary lobe), One 150kW water heater,
System Layout		
Equipment Inside Solids Processing Building	Sludge Bin and Pulper Feed Pumps	Sludge Bin and THP Feed Pumps
Equipment Located at THP Equipment Pad	B-2 System Container, Air Compressor Skid, Process Gas Compressor Skid,	Inline Dynamic Mixers, Exelys Reactor, Expansion Tank and odor control system, cooling and dilution water pump skid, cooling heat exchangers, pressure holding pumps
Equipment Inside Digester Building	Cooling Heat Exchangers, Cooling Water Pumps, Sludge Recirculation Pumps	FOG pasteurization skid
Hydraulic Considerations		
Hydrolyzed Sludge Conveyance	5fps In 4-inch lines (diluted at 4:1 ratio with digested sludge as carrier fluid) ~ 300 feet	8% hydrolyzed sludge @ 1-4 fps in 2.5-inch pipe for ~ 300 ft
<u>FOG Conveyance</u> From Storage to Treatment From Treatment to Digesters	4-10% FOG conveyed ~ 175 feet Included in Hydrolyzed Sludge Conveyance	4-10% FOG conveyed ~ 120 feet Pasteurized FOG conveyed ~ 200 feet
Plant Reuse Water Demand	60-130gpm	107-297gpm
Instrumentation and Controls		
PLC	Allen Bradley CompactLogix	Allen Bradley ControlLogix[2]
Electrical Requirements		
Phase 1 Power Consumption (Year 2025)	473,040 kWh/year	1,462,920 kWh/year
Phase 2 Power Consumption (Year 2040)	543,120 kWh/year	1,462,920 kWh/year
Performance Guarantees		
Steam Demand at 18% DS	350 lb / WT	~588 lb / WT
% Volatile Solids Reduction	48%[1]	47-51%[1]

[1] Kruger calculated the actual solids retention time (SRT), given the digester volume and feed rate for each scenario. Cambi used a set SRT of 15 days.
[2] Kruger has provided ControlLogix per their standards. They have submitted a deduct to provide CompactLogix if the City requires it.

Economic Analysis

CDM Smith's economic analysis included calculation of the estimated capital cost to purchase and construct each THP system and the anticipated annual operation and maintenance (O&M) cost of each system.

The capital and O&M costs developed for each THP system are comparative costs calculated in order to determine the relative installation and operating costs of each THP system. Because these costs are comparative in nature, certain common elements were removed where they were considered to be identical among options. The capital and O&M costs presented in this TM are not intended to be a comprehensive representation of total cost, but instead an indication of the relative cost between options for the purpose of comparing the systems. Neither the capital nor the O&M costs presented in this TM should be used for budgeting purposes.

The estimated capital and O&M costs were subsequently used to calculate the net present cost (NPC) of each system. The following sections discuss the economic components and the assumptions made in CDM Smith's calculations.

Capital Costs

THP System Equipment Costs

Capital costs associated with the THP system included the supplier system cost as well as spare parts, an 18-month warranty period and warranty bond. The four items listed below were added to the system supplier's base system cost to capture the differences in capital cost for items that are outside of the THP scope, but are affected by the THP system supplied.

- Combined Heat and Power (CHP) system.
- Process yard piping (sludge piping) between the THP system and the digesters.
- Pre-engineered metal canopy that will cover the THP equipment pad.
- A concrete expansion tank on the THP equipment pad adjacent to the Exelys reactor. This in-ground, cast-in-place tank is required as part of Kruger's Exelys system for odor control and rare over-pressurization events. At Kruger's request, the tank will be provided by the General Contractor.

Additional Capital Cost Assumptions

The following assumptions were incorporated into the capital costs presented in **Table 3.**

- Installation costs and site work for both systems were assumed to be relatively equal and are not included.
- Conceptual opinions of probable construction cost (OPCCs) were prepared by CDM Constructors Inc. (CCI) for each system supplier's combined heat and power system; sludge piping between the THP system and the digesters; expansion tank; and a pre-engineered metal canopy to cover the structure.
- Construction cost markups were as follows.
  - Permits: 0.5 percent of total direct costs.
  - Sales Tax: 9.25 percent.

- Builder's Risk: 0.5 percent of total capital cost.
- General Liability: 1.0 percent of total capital cost.
- Bonds & Insurance: 1.5 percent of total capital cost.
- General Conditions: 10 percent of subtotal prior to overhead & profit.
- Contractor's Overhead & Profit: 10 percent of subtotal after addition of the markups in the previous bullets.
- Construction Contingency: 25 percent of subtotal after overhead & profit is applied.
- Escalation to midpoint of construction: 4.79 percent of cost at today's dollars. The midpoint of construction was assumed to be July 2016.

Table 3: THP System Comparative Capital Costs

Economic Factor	Cambi Inc. B-2 THP System Phase 1	I. Kruger Inc. Exelys System Phase 1	Cambi Inc. B-2 THP System Phase 2	I. Kruger Inc. Exelys System Phase 2
Base System Cost				
THP System Equipment	$2,929,035	$3,568,610	$167,629	$35,000
18-Month Warranty	$12,000	$17,760	$0	$0
Payment and Performance Bonds	$90,000	$24,120	$0	$0
60 Day Operator Shadowing and Optimization	$60,000	$70,000	$0	$0
Adders Supplied by THP System Supplier				
Optional One-Year Service Contract[1]	$521,700	$198,000[2]	$0	$0
Additional Project Requirements				
Process Yard Piping	$141,755	$46,612	$71,559	$13,120
Pre-Engineered Metal Canopy	$83,984	$112,917	$0	$0
Combined Heat and Power System[3]	$2,077,910	$2,391,212	$0	$0
Concrete Expansion Tank	N/A	$38,002	N/A	$0
Total Direct Costs	**$5,394,684**	**$6,269,233**	**$239,188**	**$48,120**
Permits	$26,973	$31,346	$1,196	$241
Sales Tax	$319,193	$348,411	$15,506	$3,238
Builder's Risk	$45,120	$52,255	$2,010	$405
General Liability	$90,240	$104,510	$4,020	$810
Bonds & Insurance	$135,360	$156,765	$6,030	$1,215
Subtotal Prior to OH&P	**$6,011,570**	**$6,962,521**	**$267,949**	**$54,028**
General Conditions	$601,157	$696,252	$26,795	$5,403
Contractor's Overhead & Profit	$601,157	$696,252	$26,795	$5,403

Subtotal with OH&P	**$7,213,884**	**$8,355,025**	**$321,539**	**$64,834**
Construction Contingency	$1,803,471	$2,088,756	$80,385	$16,208
Total Cost at Today's Dollars	**$9,017,356**	**$10,433,781**	**$401,924**	**$81,042**
Escalation to Midpoint of Construction	$432,121	$500,476	$19,261	$3,884
TOTAL CAPITAL COST	**$9,449,000**	**$10,944,000**	**$421,000**	**$85,000**

[1] Optional One-Year Service Contract is not included in the capital cost. See *Non-Economic Analysis* below for more details.

[2] Kruger's cost does not include 24 hours a day, seven days a week coverage.

[3] Kruger's exceptions to the design were taken into account in a separate analysis. The results are discussed in the Summary and Recommendation Section.

N/A: Not applicable to THP system supplier's design.

Operation and Maintenance Costs

Each THP system supplier provided a motor list for all equipment within the THP scope of supply, as well as maintenance costs that take into account all equipment supplied within their scope. Additionally, each THP system's performance guarantees (percent volatile solids reduction and steam demand) were used to calculate the cost of generating steam.

CDM Smith's calculation of estimated annual O&M costs included the following assumptions.

- Based on updated project biosolids loadings and FOG deliveries, CDM Smith estimated average day and maximum month solids loading to the THP system for initial startup (Year 2018), Phase 1 design (Year 2025) and Phase 2 (Year 2040). CDM Smith assumed linear growth for solids loading between the initial startup, Phase 1 and Phase 2 design years; these annual loads will be applied to costs that are a function of the solids loading.

- The two components of the O&M cost are THP O&M costs and CHP O&M costs.

  - **THP O&M costs** include the cost of electrical consumption and the cost of maintaining the system. The maintenance costs were entered directly into the calculation from data submitted by the THP suppliers. The electrical consumption (operating cost) was estimated from the motor lists submitted with the THP supplier's proposals. The kilowatt hour (kWh) demand for each motor was calculated from the nameplate motor horsepower and its operating time. The majority of the motors listed either had 100 percent operating time (duty equipment) or 0 percent operating time (standby equipment). The exception is Kruger's FOG pasteurization system, which is a batch process with a water heater. Based on information supplied by Kruger, it was assumed that the water heater would only be operating 15 minutes per hour.

    The cost of electricity consumed was determined from the U.S. Energy Information Association's (EIA) data on the cost per kWh delivered to industrial users in Tennessee; it was assumed that the 2014 annual average price will experience 3 percent inflation per year through 2040.

- **CHP O&M costs** were estimated from the cost of natural gas consumption, the savings from CHP electrical generation, and the maintenance costs of the CHP system.

  - **The cost of natural gas consumption** was estimated from the performance guarantees. The percent volatile solids reduction performance guarantee was entered into CDM Smith's mass balance to determine the amount of methane gas (digester biogas) available as fuel for the CHP engine. The maximum month steam demand performance guarantee was used to size the CHP engines for each THP system supplier. Using data from the engine manufacturer, CDM Smith determined the British thermal units (BTU) of fuel needed to produce the required steam demand. The difference between the fuel needed for the CHP engine to produce the required steam, and the fuel available in the form of biogas, is the amount of fuel that has to be purchased as natural gas.

    The cost of natural gas was determined from EIA data on the cost and heat value of natural gas delivered to industrial users in Tennessee; it was assumed that the 2014 annual average price will experience 3 percent inflation per year through 2040. Given the volatility of natural gas prices, a sensitivity analysis was conducted on the natural gas price to see how it affected the economic evaluation; this is discussed in the *Summary and Recommendations* section.

  - **The savings from CHP electrical generation** was estimated from the steam demand performance guarantee. As discussed above, the maximum month steam demand was used to size the CHP engine for each THP supplier. Using data from the engine manufacturer, CDM Smith determined the amount of electricity the engine would generate while producing the required steam demand.

    The value of the electricity generated was determined from EIA data on the cost per kWh delivered to industrial users in Tennessee; it was assumed that the 2014 annual average price will experience 3 percent inflation per year through 2040.

  - **The maintenance cost of the CHP system** was estimated as a function of the amount of electricity generated. The vendor who provided the quotes for the CHP system instructed CDM Smith to assume a maintenance cost equal to $0.016 per kW generated by the engine. This is within the range of expected maintenance costs ($0.009-$0.025 per kW) published by the United States Environmental Protection Agency (EPA) Combined Heat and Power Partnership.

The estimated annual O&M costs for Cambi and Kruger are presented in **Table 4** and **Table 5,** respectively**.** Note that costs are shown as a negative value, and revenue is shown as a positive value.

Table 4: Summary of Estimated Annual O&M Cost/Revenues for Cambi

Calendar Year	Year of Operation	THP Maintenance Costs	THP Electrical Consumption Costs	CHP Maintenance Costs	CHP Natural Gas Consumption Costs	CHP Electrical Generation Revenues	Total O&M Costs
2018	1	-$33,700	-$37,200	-$69,900	-$134,900	$345,200	$69,500
2019	2	-$33,700	-$38,300	-$73,000	-$144,900	$371,600	$81,700
2020	3	-$33,700	-$39,400	-$76,200	-$155,500	$399,300	$94,500
2021	4	-$33,700	-$40,600	-$79,300	-$166,500	$428,300	$108,200
2022	5	-$33,700	-$41,900	-$82,500	-$178,100	$458,700	$122,500
2023	6	-$33,700	-$43,100	-$85,600	-$190,300	$490,600	$137,900
2024	7	-$33,700	-$44,400	-$88,800	-$203,000	$523,900	$154,000
2025	8	-$33,700	-$45,700	-$92,000	-$216,200	$558,800	$171,200
2026	9	-$33,700	-$47,100	-$95,500	-$231,200	$598,000	$190,500
2027	10	-$33,700	-$48,500	-$99,100	-$246,800	$638,900	$210,800
2028	11	-$33,700	-$50,000	-$102,700	-$263,200	$681,900	$232,300
2029	12	-$33,700	-$51,500	-$106,300	-$280,400	$726,800	$254,900
2030	13	-$33,700	-$53,000	-$109,800	-$298,300	$773,800	$279,000
2031	14	-$33,700	-$54,600	-$113,400	-$317,100	$822,900	$304,100
2032	15	-$33,700	-$56,200	-$117,000	-$336,700	$874,300	$330,700
2033	16	-$33,700	-$57,900	-$120,600	-$357,200	$928,100	$358,700
2034	17	-$33,700	-$59,700	-$124,100	-$378,600	$984,300	$388,200
2035	18	-$33,700	-$61,500	-$127,700	-$401,000	$1,043,000	$419,100
2036	19	-$33,700	-$63,300	-$131,300	-$424,500	$1,104,400	$451,600
2037	20	-$33,700	-$65,200	-$134,900	-$448,900	$1,168,500	$485,800
2038	21	-$33,700	-$67,200	-$138,400	-$474,400	$1,235,400	$521,700
2039	22	-$33,700	-$69,200	-$142,000	-$501,100	$1,305,400	$559,400
2040	23	-$33,700	-$71,300	-$145,600	-$528,900	$1,378,400	$598,900

Table 5: Summary of Estimated Annual O&M Cost/Revenues for Kruger

Calendar Year	Year of Operation	THP Maintenance Costs	THP Electrical Consumption Costs	CHP Maintenance Costs[1]	CHP Natural Gas Consumption Cost[1]	CHP Electrical Generation Revenues[1]	Total O&M Costs
2018	1	-$65,200	-$115,800	-$102,400	-$257,100	$505,900	-$34,600
2019	2	-$65,200	-$119,300	-$107,000	-$277,200	$544,700	-$24,000
2020	3	-$65,200	-$122,900	-$111,700	-$298,300	$585,400	-$12,700
2021	4	-$65,200	-$126,600	-$116,300	-$320,400	$628,100	-$400
2022	5	-$65,200	-$130,400	-$121,000	-$343,600	$672,800	$12,600
2023	6	-$65,200	-$134,300	-$125,600	-$367,900	$719,600	$26,600

2024	7	-$65,200	-$138,300	-$130,300	-$393,300	$768,600	$41,500
2025	8	-$65,200	-$142,500	-$134,900	-$420,000	$819,900	$57,300
2026	9	-$65,200	-$146,700	-$140,200	-$450,100	$877,700	$75,500
2027	10	-$65,200	-$151,100	-$145,500	-$481,600	$938,300	$94,900
2028	11	-$65,200	-$155,700	-$150,800	-$514,700	$1,001,700	$115,300
2029	12	-$65,200	-$160,300	-$156,100	-$549,300	$1,068,100	$137,200
2030	13	-$65,200	-$165,200	-$161,500	-$585,500	$1,137,500	$160,100
2031	14	-$65,200	-$170,100	-$166,800	-$623,300	$1,210,200	$184,800
2032	15	-$65,200	-$175,200	-$172,100	-$663,000	$1,286,200	$210,700
2033	16	-$65,200	-$180,500	-$177,400	-$704,400	$1,365,700	$238,200
2034	17	-$65,200	-$185,900	-$182,700	-$747,700	$1,448,700	$267,200
2035	18	-$65,200	-$191,500	-$188,000	-$793,000	$1,535,600	$297,900
2036	19	-$65,200	-$197,200	-$193,300	-$840,400	$1,626,300	$330,200
2037	20	-$65,200	-$203,100	-$198,600	-$889,800	$1,721,100	$364,400
2038	21	-$65,200	-$209,200	-$203,900	-$941,500	$1,820,100	$400,300
2039	22	-$65,200	-$215,500	-$209,300	-$995,500	$1,923,600	$438,100
2040	23	-$65,200	-$222,000	-$214,600	-$1,051,900	$2,031,600	$477,900

[1] Kruger's exceptions to the design were taken into account in a separate analysis. The results are discussed in the Summary and Recommendation Section.

Net Present Cost Calculation

The following assumptions were incorporated into the NPC calculation.

- Because THP pre-treatment is required year-round to achieve Class A biosolids, the THP system will be required to operate continuously.
- The calculation includes a time period of 23 years, a discount rate of 5 percent, and a 3 percent inflation rate.
- THP capital costs will be incurred in 2016 for Phase 1 construction, and Year 2023 for Phase 2 construction.
- 2018 will be the new system's first full year of operation.

The results of the NPC analysis are summarized below in **Table 6.** Note that costs are shown as a negative value, and revenue is shown as a positive valve. Detailed NPC tables are attached to this memorandum in **Appendix C** as **Table C-1.**

Table 6: Summary of Net Present Cost Analysis

Economic Factor	Cambi Inc. B-2 System	I. Kruger Inc. Exelys System
Calculation of NPC of THP O&M Costs		
NPC of THP Electrical Consumption Costs	-$889,000	-$2,770,000
NPC of THP Maintenance Costs	-$586,000	-$1,133,000
Total NPC of THP O&M Costs	-1,475,000	-3,903,000
Calculation of NPC of CHP O&M Revenue		
NPC of CHP Natural Gas Consumption Costs	-$4,939,000	-$9,687,000
NPC of CHP Electrical Generation Revenue	$12,803,000	$18,825,000
NPC of CHP Maintenance Costs	-$1,804,000	-$2,652,000
Total NPC of CHP O&M Revenue	$6,060,000	$6,486,000
Calculation of Total NPC		
Total NPC of Annual O&M Revenue	$4,585,000	$2,582,000
Total NPC of Capital Costs	-$9,447,000	-$10,603,000
Total NPC	**-$4,862,000**	**-$8,021,000**
Rank	1	2

Cambi's proposed system had the lowest total NPC due to its low base system pricing and its low O&M costs.

Discussion of Economic Analysis

THP System Electrical Costs

Cambi has a lower THP electrical consumption primarily because its system uses lower horsepower pumps. The majority of Kruger's pumps have to operate against the same pressures experienced in the Exelys reactor (~145 psi). Cambi's pumps do not have to pump into a pressurized reactor; Cambi's reactor feed pumps only pump sludge into a reactor when the reactor is empty and depressurized. Additionally, Kruger has the added electrical draw of a 150 kW electric water heater as part of its FOG pasteurization skid.

THP System Maintenance Costs

Cambi also had a significantly lower THP maintenance cost than Kruger; most of this difference was realized in the costs of pump maintenance. Kruger's annual pump-related maintenance costs ($42,633) were significantly higher than Cambi's ($26,412) and are likely attributed to the larger horsepower pumps associated with the Exelys system. Larger horsepower pumps will have a slightly higher material cost, but the true difference in cost is the frequency with which the rotors have to be replaced. Both Cambi and Kruger budgeted to replace the stator once a year; however, Kruger budgeted to replace their rotors twice a year, whereas Cambi will only replace their rotors once every three years. Stated another way, the operating life of Cambi's rotors is six times greater than that of Kruger's rotors.

Cambi's projected maintenance costs for Franklin's pumps is approximately equal to the operational data provided for Cambi's Chertsey, UK installation, which is processing flows equal to Franklin's 2040 maximum month loading. Kruger did not provide operating plant data for an Exelys installation, so no comparison could be made.

Below are some other notable comparisons of the two supplier's maintenance costs.

- Cambi listed approximately $5,800 per year of maintenance for pressure related equipment and $700 for compressors, while Kruger listed $0 for both.
- Cambi listed approximately $800 per year for valve maintenance, while Kruger listed $0.
- Kruger has approximately $7,400 per year to replace the media on its odor control, while Cambi has listed $0 for odor control.
- Kruger has approximately $14,900 per year of maintenance associated with its inline dynamic mixer, which is specific to the Exelys process.
- Kruger listed $14,750 per year of maintenance associated with its sludge storage bin system, while Cambi listed approximately $5,000. Kruger included the repair and replacement of the shafts and flights of the screws, but Cambi did not. Because the storage bins for the two systems are providing the same function and are relatively equal, CDM Smith did not view this maintenance cost as appropriate for inclusion in this analysis. Since this is a comparison report, it was assumed the realized maintenance costs for these bins would be relatively equal, and this line item was therefore removed from the total maintenance cost for the Kruger and Cambi systems.

CHP System Natural Gas Costs

The Kruger system required the purchase of more natural gas as supplemental fuel for its CHP system. Cambi had a significantly lower steam demand than Kruger, which resulted in a smaller CHP engine and less fuel to create the required steam compared to Kruger's system. Since Kruger and Cambi both had similar percent volatile solids reduction guarantees, there was approximately the same amount of biogas available for the CHP engines for both systems. This means that for the same solids loading, the Kruger system requires the purchase of more natural gas to thermally hydrolyze the incoming solids than Cambi.

CHP System Electrical Generation Savings

The production of electricity on site reduces the amount of electricity the City has to purchase from the grid, resulting in electrical cost savings. As a result of Kruger's need for a larger CHP engine and more fuel to produce the required steam, the Kruger CHP engine generated much more electricity than Cambi's CHP engine. The difference in electrical savings between Kruger and Cambi more than offset the difference in natural gas costs between the two suppliers.

Non-Economic Analysis

In addition to the economic evaluation, CDM Smith evaluated each THP system according to five non-economic criteria. Each non-economic criterion was given a raw score on a scale of 1 (most desirable) to 5 (least desirable) and weighted on a scale of 1 (low priority) to 5 (high priority). The raw score for each criterion was multiplied by its respective weighting, and the five weighted scores were added together to obtain the Raw Non-Economic Score on a scale of 0 to 85 points. In general, a low score indicated that the system is reliable and well-supported by its system supplier.

The non-economic criteria and their definitions and weights are described below.

- **Level of Thermal Hydrolysis Experience.** This criterion captures the overall THP experience the system supplier has with thermal hydrolysis. It takes into account the amount of years the proposed system has been manufactured and the number of worldwide, fully operational thermal hydrolysis systems installed. The more installations a system has, the better the track record. More installations illustrate demand and satisfaction for a system, and similar to the number of years the system has been manufactured, it also ensures that the system has had its "bugs" worked out in full scale applications. This criterion received a high weighting of 5, because it is critical that the THP system operate properly with only infrequent shutdowns for maintenance. The longer a system has been manufactured and the more worldwide full scale installations, the lower the score the supplier received.

- **Relative ability to provide responsive support after startup.** This criterion addresses the strength of the supplier and its ability to support the installed THP system. A lower score is provided to the supplier who has a larger number of employees available to provide service. This criterion received a medium weighting of 3, illustrating the balance between the City's desire to have on-site support and the recommendation from both suppliers that the most appropriate form of support for Franklin would be through remote monitoring.

- **Company Revenue.** Company revenue is an attempt to quantify the financial stability of the company. Because it is not in the scope of this pre-selection to conduct a complete analysis of the financial stability of the two system suppliers, annual revenues were used as a rough gauge of the size and stability of the company. This criterion received a medium weighting of 3 and reflects the importance of the strength and longevity of the company, as it is in the City's best interest for the supplier to be around to provide support for the system for decades to come. The supplier who earned higher annual revenues received a lower score.

- **Terms and Conditions.** This criterion received a high weighting of 4 since the terms and conditions have the potential to affect schedule and budget. The fewer exceptions the supplier made to the terms and conditions set forth by CDM Smith in the pre-selection package, the lower the score.

- **New features of designs.** This criterion captures the risk associated with the presence of new, less tested, features included in a proposed THP system. Because they are new, these features do not have the same track record as the rest of the established system. This criterion received a low weighting of 2 because the risk of process downtime that could be caused by these new features is minimal relative to installations and years manufactured. The greater number of changes, and more significant the design changes, the higher the score the system received.

Discussion of Non-Economic Analysis

Level of THP Experience

Cambi has been manufacturing its THP systems for 20 years compared to four years for Kruger's Exelys system. However, until the past three years, all of Cambi's systems had utilized its larger B-12 reactors. Cambi started manufacturing its smaller B-2 and B-6 reactors in order to better suit the needs of the majority of the market. The B-2 and B-6 systems are essentially the same as the B-12 systems that have been being manufactured for two decades with the exception of their size and method of mixing the pulper. The B-12 reactors hold approximately 12 cubic meters of sludge per batch, compared to 2 cubic meters for the B-2 reactors. The B-12 system has dedicated pulper mixing pumps, and the B-2 system relies on the steam being injected into the pulper to provide the required mixing. Cambi claims the smaller volume of sludge in the B-2 pulper is thoroughly mixed by the steam injection alone.

Before it began manufacturing the Exelys system four years ago, Kruger had been manufacturing the Biothelys system for 10 years. However, the differences between the Biothelys and Exelys systems (batch vs continuous flow) are more dramatic than the differences between Cambi's B-12 and B-2 systems. Since the years a system has been manufactured is used to measure how many "bugs" have been worked, Kruger's Biothelys experience has very little relevance to Kruger's Exelys experience. Therefore Cambi would receive a better score for the manufacturing portion of this criterion..

The other part of the *Level of THP Experience* criterion is the number of worldwide installations. Cambi and Kruger submitted 48 and 4 worldwide installations, respectively. However, this criterion was intended to measure the number of installed units in full scale operation. After reviewing the details of the installation lists, CDM Smith determined that Cambi had at least 29 plants in full operation by the close of 2014, and Kruger had one Exelys system that was still just finishing startup. Kruger also has seven installed Biothelys systems worldwide; this experience is valuable, but as explained earlier, the Biothelys experience doesn't carry as much weight when measuring

Kruger's experience for the proposed Exelys system. Since Cambi has significantly more full scale installations, and more years of relevant manufacturing experience than Kruger, Cambi received a score of 1 and Kruger received a score of 4 for this criterion.

Relative Ability to Provide Support After Startup

This criterion was intended to gauge the level of support Franklin could expect to receive after startup. Cambi currently has seven U.S. employees, none of whom are located in Tennessee. However, four of these U.S. employees have direct THP O&M experience. On the other hand, Kruger has 3,500 U.S. employees, a number of whom are located in Tennessee and have O&M experience. Despite this large U.S. presence, it is unclear whether any of Kruger's U.S. employees have any O&M experience with the Exelys system. Kruger does possess a very strong O&M group that operates large and complex facilities across the US.

Another consideration taken into account is that Cambi will have to split its O&M staff responsibilities to its other installations worldwide, and more importantly, its large number of new installations being installed in the next two to three years. On the other hand, an Exelys system at the Franklin WRF would represent Kruger's only THP installation in the U.S., in a state where the company already has a strong, established O&M presence, close to Kruger's national headquarters. Because of these factors, and Kruger's established relationship with the City, Kruger received the most desirable rating for this criterion and Cambi the least desirable.

Company Revenue

Kruger/Veolia is a much larger, more established firm than Cambi. This difference is illustrated in the 2013 company revenues. Kruger's revenues are more than five times greater than Cambi's revenues, which is why Kruger and Cambi were given ratings of 1 and 5, respectively. This criterion weight was given a 3 instead of a 5 because of the liberties and assumptions that had to be made in providing this score.

The company revenue is only chosen as an indicator of the company's ability to provide service for their proposed system for decades to come. One flaw in this criterion is that high revenues do not necessarily equal financial stability. Secondly, comparing Cambi's revenues to Kruger/Veolia's is not an apples-to-apples comparison of the supplier's likelihood to support the system into the future. Cambi's business revolves around THP, but THP is a small niche in one of Kruger/Veolia's markets. Comparing Cambi's revenue to Kruger/Veolia's Biosolids and Bioenergy group may be more appropriate. However, because it is difficult to quantify these variables with the available information, CDM Smith has chosen to score this criterion based on company revenue.

Terms and Conditions

Kruger expressed significant exceptions to the terms and conditions set forth in the pre-selection package, which were provided as a means to protect the Contractor, and ultimately the City from delays resulting from one-sided negotiations by a pre-selected vendor. Kruger has generally stated that they do not agree to the terms and conditions presented in the pre-selection package, and will negotiate the terms and conditions with the Contractor.

CDM Smith's intent in establishing the terms and conditions was to save time and money during the construction phase. If the Contractor is told they must use the selected supplier, the selected supplier has no incentive to negotiate in good faith; in other words, the Contractor does not have the choice of going somewhere else. As an example of the issues this would cause, the supplier could put the Contractor in the position of potentially having to make claims for delays that are caused by the supplier.

New Features of Designs

Cambi's new design features include a reduction of phases in the batch reactor process from five stages to four. This design change has increased the throughput capacity for a given system. Additionally, Cambi has provided control valves on each of the steam lances that inject steam into the reactors. This design change allows Cambi to pace the flow of steam injected into a reactor, and it allows for the use of high bursts of steam to clean a lance. These changes have been tested at the Chertsey, UK plant for two years and are now being included in all B-2 and B-6 systems.

Kruger's mode of steam injection has changed from lances to an inline dynamic mixer. This design change has allowed Kruger to significantly reduce the pressure of the steam required, and it has also eliminated the maintenance issue of steam lances becoming clogged or damaged by rags or other debris. This technology is installed at Kruger's installation at Lille, France. It is also important to note that the Franklin WRF would be the first Exelys installation set up as an LD design, meaning that the THP pretreatment is occurring upstream of anaerobic digestion. All other Exelys installations, designs or demonstration units are set up as DLD or DL, with thermal hydrolysis occurring downstream of anaerobic digestion. Kruger does have LD design experience with its seven installed Biothelys systems.

Kruger's new feature includes a complete change in how steam (heat) is injected into the system. Cambi's new feature includes the addition of control valves onto steam lances that have always been a part of the design. Cambi's new feature is less of a deviation from the original design, and so it received a slightly better score.

Cambi's operational process change from five phases in the batch process to four is an optimization change and has been tested. Kruger's operational change from a DLD configuration to an LD configuration is a greater deviation, and brings with it more risk. Therefore, Cambi will also receive a slightly better score than Kruger for these items.

The results of the non-economic scoring are presented in **Table 7.** The complete non-economic scoring table is included in Appendix C as **Table C-2.** The Cambi system received the lowest (most favorable) score due to its number of installations, the number of years the system has been manufactured, and Cambi's acceptance of the terms and conditions.

Table 7: Summary of Non-Economic Scoring

Parameter	Cambi Inc. B-2 System	I. Kruger Inc. Exelys System
Raw Non-Economic Evaluation Score (out of 90 points)	45	54
Rank	1	2

Final Scoring

Table 8 presents the calculation of the final Total Score for each THP system. The method by which the Total Score was calculated is described below.

- The economic score and the non-economic score each received equal weighting of 50 percent. This equal weighting indicates that each THP system's non-economic attributes carry equal importance compared to its capital, operating and maintenance costs.
- The Raw Economic Score for a THP system is based on its NPC, and was assigned on a scale from 0 to 100, with a score of 50 being neutral. When performing an economic analysis, it is important to provide numerical scores that are relative to the NPC of the options that are being evaluated. Typically this is done by determining the standard deviations in the NPC, and the average NPC and assigning scores that are relative to the standard deviation of a given cost from the average cost. Since there are only two scores, this scoring method will not work. Therefore, it was determined that each system supplier's score would have an equal numerical distance from a score of 50. Also, the scores would be proportional to the difference in their NPC. Kruger's NPC is 65 percent greater than Cambi's NPC, so Kruger received a Raw Economic Score that is 65 percent greater than Cambi's raw score. Because the Raw Non-Economic Score from Table C-2 is on a scale of 0 to 85 points, it was first normalized to a 0- to 100-point scale, then multiplied by the 50 percent weighting factor to obtain the Weighted Non-Economic Score.
- The Total Score is the sum of the Weighted Economic Score and the Weighted Non-Economic Score and is expressed on a scale of 0 to 100 points. The lowest Total Score indicates the preferred THP system.

Table 8: Final Scoring of THP Systems

Parameter	Cambi Inc. B-2 System	I. Kruger Inc. Exelys System	
Calculation of Weighted Economic Score			
Total NPC	($4,862,000)	($8,021,000)	164.97%
Raw Economic Score (0 to 100 points)	37.74	62.26	164.97%

Weighted Economic Score (50% of Total Score)	*50%*	*18.9*	*31.1*
Calculation of Weighted Non-Economic Score			
Raw Non-Economic Evaluation Score (0 to 85 points)		45	54
Normalized Non-Economic Evaluation Score (0 to 100 points)		52.9	63.5
Weighted Non-Economic Score (50% of Total Score)	*50%*	*26.5*	*31.8*
Calculation of Total Score			
Total Score (0 to 100 points)		***45.3***	***62.9***
Rank		1	2

Cambi received the lowest (best) total score of the two system suppliers.

Discussion

Kruger Design Alternatives

It is important to note that Kruger proposed design alternatives that they believe offer advantages to the City of Franklin. The first design alternative was the elimination of the sludge screens upstream of the proposed Exelys system. Kruger has stated one of the main advantages of the Exelys system over Cambi's B-2 system is that the Exelys system does not require upstream sludge screening. The Exelys method of steam injection is through an inline dynamic mixer. Kruger believes that this mixer is not as susceptible to damage and requires less maintenance from debris than Cambi's steam lances. This difference was not included in the main part of the evaluation because the Engineer and the City decided to include sludge screens as a best practice, regardless of the THP system supplier. The best practice being that sludge screening increases the useful life of all biosolids equipment downstream as well as to increase the marketability of the Class A product by removing undesirable trash and plastics.

The second proposed design alternative was to increase the scope of supply of the THP pre-selection package to include pre and post dewatering. As described above, the pre-dewatering of the WAS is outside of the scope of the THP suppliers; the current THP Pre-Selection instructs Kruger and Cambi to design for 18% dry solids cake to be fed into their THP process. This value was based off of a centrifuge pilot, which took place at Franklin in August 2014; the pilot achieved a range of 19-22% dry solids cake. Designing the THP systems for 18% ensures that the THP systems have the capacity to process the design loads when the centrifuges are not operating optimally. By including the pre-dewatering centrifuges into Kruger's scope of supply, Kruger could potentially design around 22% cake solids by guaranteeing the centrifuge performance. This is significant because it would reduce Kruger's steam demand, which would decrease the amount of natural gas purchased and also decrease the size of the CHP system needed to create the steam. On the other hand, polymer usage (i.e., another portion of the operating cost) would most likely have to increase to consistently achieve 22% cake solids.

An alternative economic analysis was carried out to evaluate the effect of incorporating Kruger's design alternatives. Kruger quoted a capital cost of $400,000 for sludge screens with a 20-year operating cost of $150,000; installation costs were estimate to be between $250,000 and $400,000 dollars. The $400,000 capital cost was added to Cambi's total direct costs (and not Kruger's), which was then marked up for permits, construction contingencies and overhead as described in the capital cost section above. The $150,000 was also added to the Cambi's O&M NPC. In addition to the cost of the sludge screens, it was assumed that Kruger could design the Exelys system around a 22% solids feed. The reduced steam demands allowed Kruger to have the same size CHP system as Cambi, thus reducing their comparative capital cost. The reduced steam demand also decreased the amount of natural gas needed to be purchased as supplemental fuel. However, it also decreased the amount of electricity generated through Kruger's CHP system. The result of the NPC evaluation is shown in Table 9 below.

Table 9: Summary of Net Present Cost Analysis with Kruger Design Alternatives

Economic Factor	Cambi Inc. B-2 System	I. Kruger Inc. Exelys System
Calculation of NPC of THP O&M Costs		
NPC of Sludge Screen O&M Costs	-$150,000	$0
NPC of THP Electrical Consumption Costs	-$889,000	-$2,770,000
NPC of THP Maintenance Costs	-$586,000	-$1,133,000
Total NPC of THP O&M Costs	-1,604,000	-3,903,000
Calculation of NPC of CHP O&M Revenue		
NPC of CHP Natural Gas Consumption Costs	-$4,939,000	-$6,727,000
NPC of CHP Electrical Generation Revenue	$12,803,000	$15,177,000
NPC of CHP Maintenance Costs	-$1,804,000	-$2,137,000
Total NPC of CHP O&M Revenue	$6,060,000	$6,313,000
Calculation of Total NPC		
Total NPC of Annual O&M Revenue	$4,435,000	$2,410,000
Total NPC of Capital Costs	-$10,055,000	-$10,129,000
Total NPC	**-$5,620,000**	**-$7,719,000**
Rank	1	2

Incorporating Kruger's design alternatives increased Cambi's capital and operating costs due to the addition of the cost of sludge screens into Cambi's analysis. The design alternative of Kruger designing the Exelys system to receive 22% solids decreased Kruger's capital cost, but also increased Kruger's operating costs; both of which were the result of the decreased steam demand for the Exelys steam. The decreased steam demand allowed Kruger to have a smaller CHP system, which reduced the capital costs. It also reduced the amount of natural gas to be purchased and the amount of electricity generated. The electrical generation provided more revenue than the additional cost of natural gas required to produce the electricity; so in reducing the amount of steam required, the Exelys system also reduced the amount of savings from electrical generation. This cut into the savings realized by the reduction in capital costs.

In summary, including Kruger's design alternatives closed the gap between the cost of the Cambi and Kruger system by approximately $1.2M, but still left the Cambi B-2 system being $2.1M less expensive than the Kruger Exelys system for this application.

Natural Gas Price Volatility Analysis

Kruger's Exelys system requires more steam demand than Cambi's B-2 system for a given solids loading. The biogas created from THP and anaerobic digestion typically doesn't contain the required quantity of BTU's that a CHP engine or boiler needs to produce the required quantity of steam. Because of this, natural gas needs to be purchased to provide the additional fuel required. If the steam is being produced in a boiler, where there is not electrical generation to produce savings, more steam equates to more natural gas which means higher operation costs. However, the proposed system at Franklin WRF is generating all the steam for the THP system through a CHP engine, which means electrical generation is directly tied to the THP system steam demand. In this case, more steam equates to more natural gas AND more electrical generation. This option was chosen by CDM Smith because the difference in prices of natural gas and electricity made this option economically attractive.

The reason that this scenario generates revenue is because the cost of natural gas is low relative to the cost of electricity. The prices of electricity are fairly steady and predictable, which is not the case for natural gas. Over the past ten years, the annual average cost of natural gas for industrial users in Tennessee has varied drastically from year to year, with the highest annual increase and decrease being 34.4% and -36.6%, respectively. The price of natural gas used in this evaluation can have a significant effect on the outcome of the economic analysis of the two vendors. Because of this, and the volatility of natural gas prices, a sensitivity analysis was conducted to determine what affect our assumptions on the natural gas price would have on the economic evaluation.

The natural gas price used in the main evaluation assumed that the 2014 annual average price of natural gas for industrial users in Tennessee would experience 3% inflation per year. To attempt to identify the range of possible natural gas prices, it was decided to run the evaluation using the lowest and highest values experienced since 2001. The low price extreme assume $4.93 per thousand cubic feet of natural gas, with zero percent inflation. The high price extreme assumed $10.98 per thousand cubic feet of natural gas with 3% annual inflation. The NPC for Cambi's B-2 and Kruger's Exelys was calculated using these natural gas prices. The results of this analysis is shown in Table 10.

Table 10: Net Present Cost (NPC) as a Function of Natural Gas Price Assumptions

	2014 Price of Natural Gas (NG) ($/1,000 cf)	Annual Inflation Rate of NG Price (%)	NPC of Cambi Inc. B-2 System	NPC of I. Kruger Inc. Exelys System
Natural Gas Pricing Assumption				
Proposal Assumption	$6.46	3%	-$4.9M	-$8.0M
Low Price Extreme Assumption	$4.93	0%	-$2.4M	-$2.9M
High Price Extreme Assumption	$10.98	3%	-$8.3M	-$14.6M

As the cost of natural gas increases and decreases, the NPC of the THP systems increase and decrease. The NPC of Kruger's Exelys system is more sensitive to the cost of natural gas than Cambi's B-2 system. Because of this, if the future cost of natural gas is less than the proposal assumptions, the difference between the NPC of Cambi and Kruger's system will decrease.

Site Visits

In addition to the final scoring in Table 8, the following information, gathered during site visits in October 2014, was incorporated into the final selection.

- City and CDM Smith staff visited a Kruger Exelys system in Lille, France. The staff liked the simplicity of the system, and noted a few things that would have to be done differently if the Exelys system was chosen for Franklin, such as more redundancy on mechanical equipment. However, the City staff was concerned that they only saw one facility, and that facility was still under construction.
- City and CDM Smith staff visited Cambi's B-12 installation at Davyhulme in Manchester, United Kingdom, in addition to another Cambi installation in Denmark, in order to familiarize themselves with the operation and maintenance of the Cambi system. The group then visited a Cambi factory to see a B-2 system, similar to what would be provided for Franklin. In general, the City was impressed with Cambi's track record, but thought the system could be intimidating because it seemed like it was more complicated than the Kruger system.

Based on the Cambi system's first-place ranking in the final scoring, CDM Smith recommends that the City select the Cambi's system for design and installation.

Summary & Recommendation

After developing an RFP for the City's new THP system, CDM Smith conducted an evaluation of two THP system suppliers' proposals for the Franklin WRF Modifications & Expansion Project. This evaluation compared each THP system on the basis of its 23-year NPC and non-cost criteria scoring. The combined cost and non-cost scoring showed that the proposed Cambi system provides a lower initial capital cost and better life cycle return on investment for the City, and has a more established track record.

CDM Smith recommends that the City select the Cambi B-2 THP system for the Modifications and Expansion Project at the Franklin WRF.

Attachments:

Appendix A – RFP & Addenda
Appendix B – Manufacturer Proposals, RFIs & Additional Information
Appendix C – NPC & Non-Economic Scoring Tables

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Project File