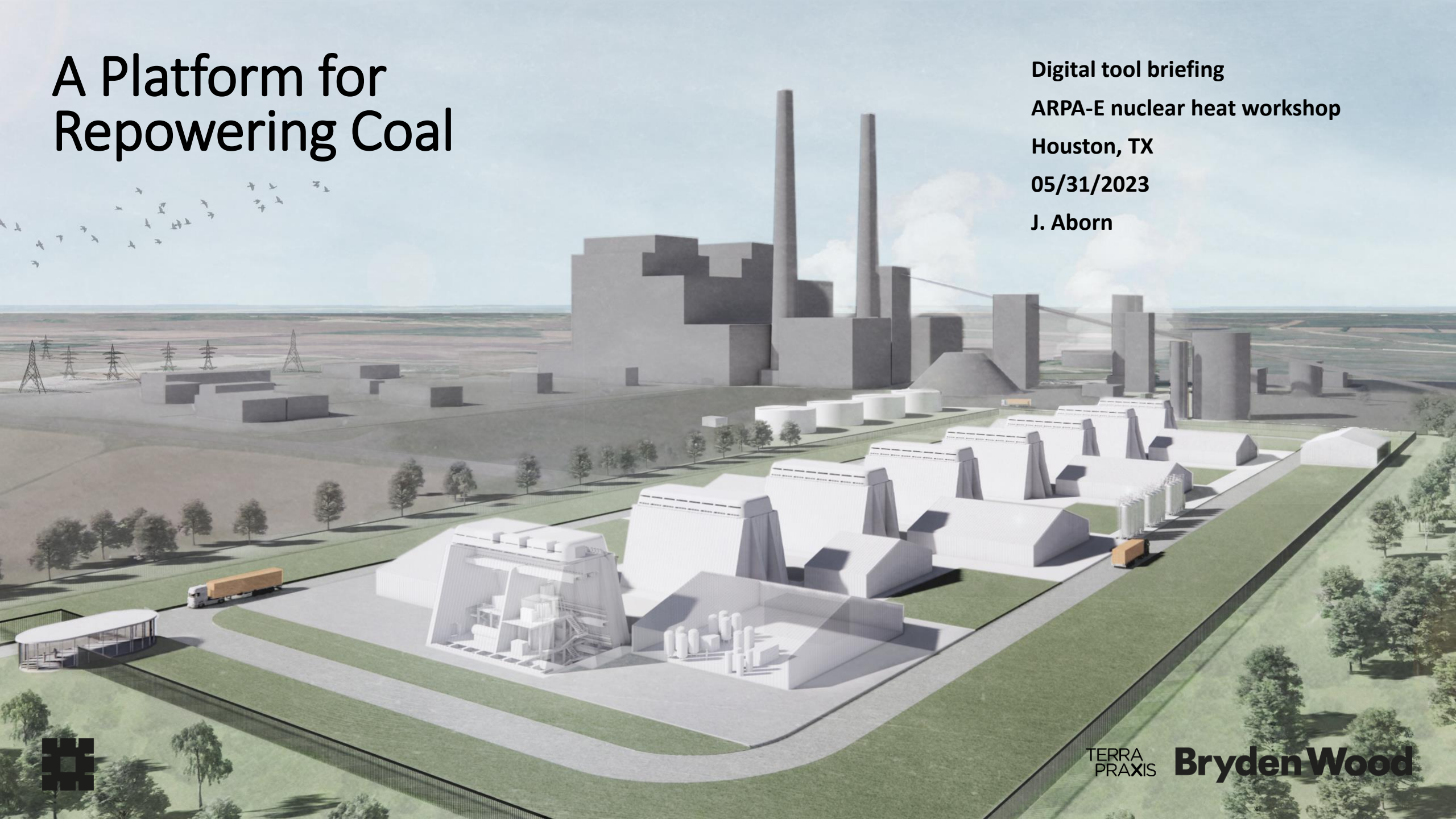


A Platform for Repowering Coal

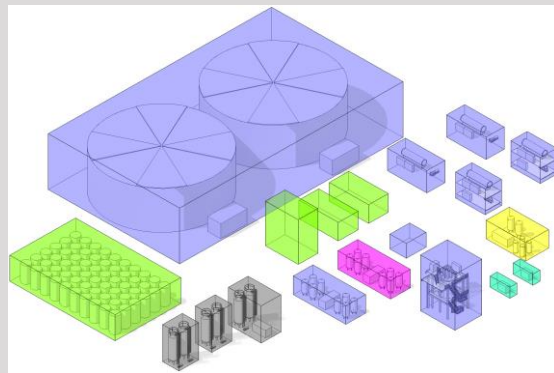
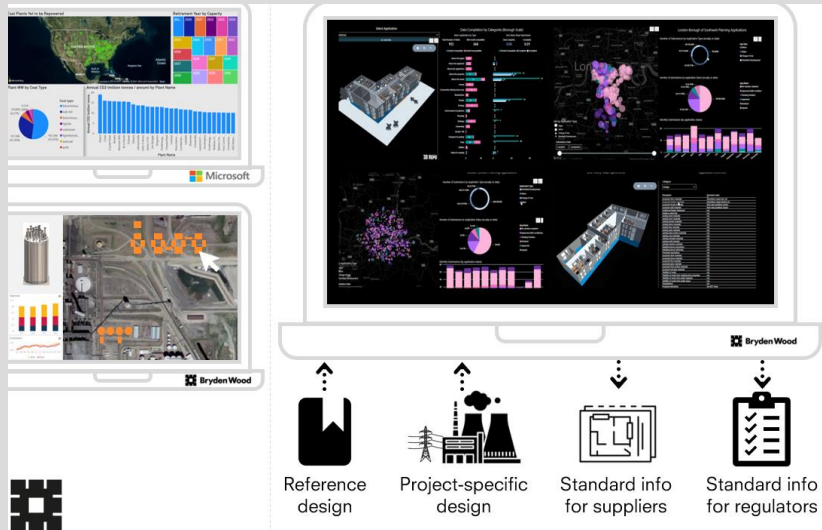
Digital tool briefing
ARPA-E nuclear heat workshop
Houston, TX
05/31/2023
J. Aborn



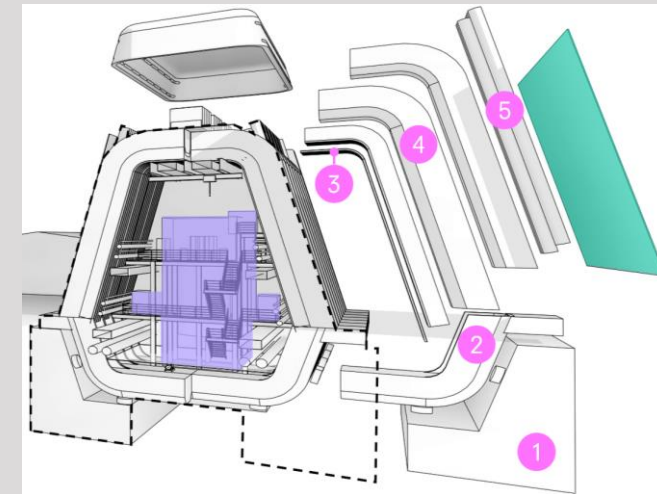
TERRA
PRAXIS

Bryden Wood

Nature of standardization

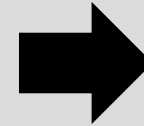
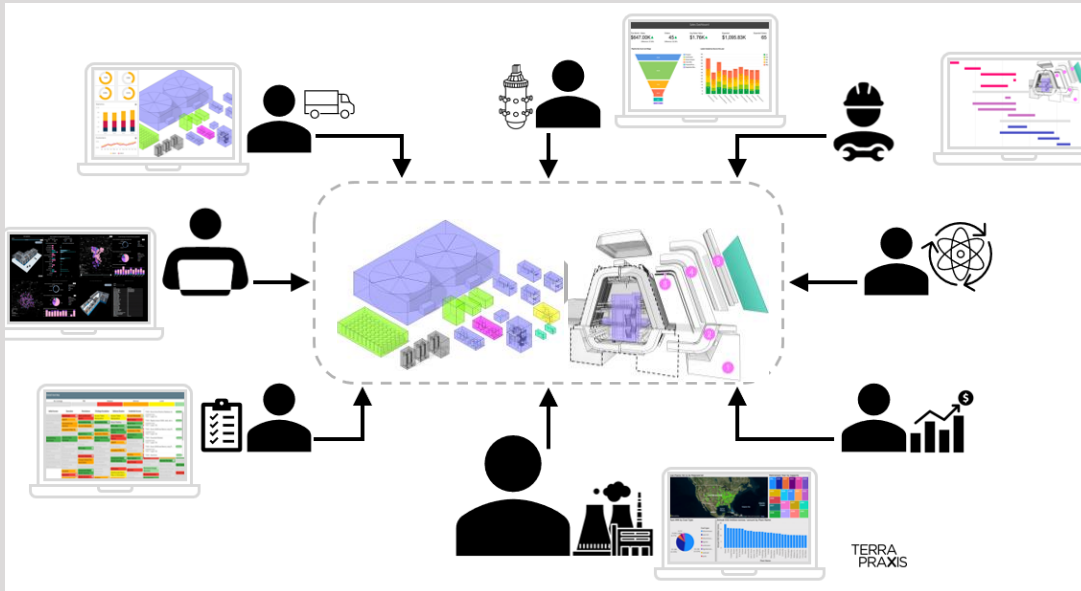


Digital Tools



Standardized Components

Nature of collaboration



1. Strategy

- Exploit high productivity parallel work
- Enable minimization of long-lead items
- Enable compatible suppliers/components
- Enable off-site fabrication & inspection
- Enable factory manufactured components
- Enable thermal energy interconnect system

2. Schedule Engineering

- Facilitate parallel delivery opportunities
- Enable multiple sources of services and components

3. Project Risk

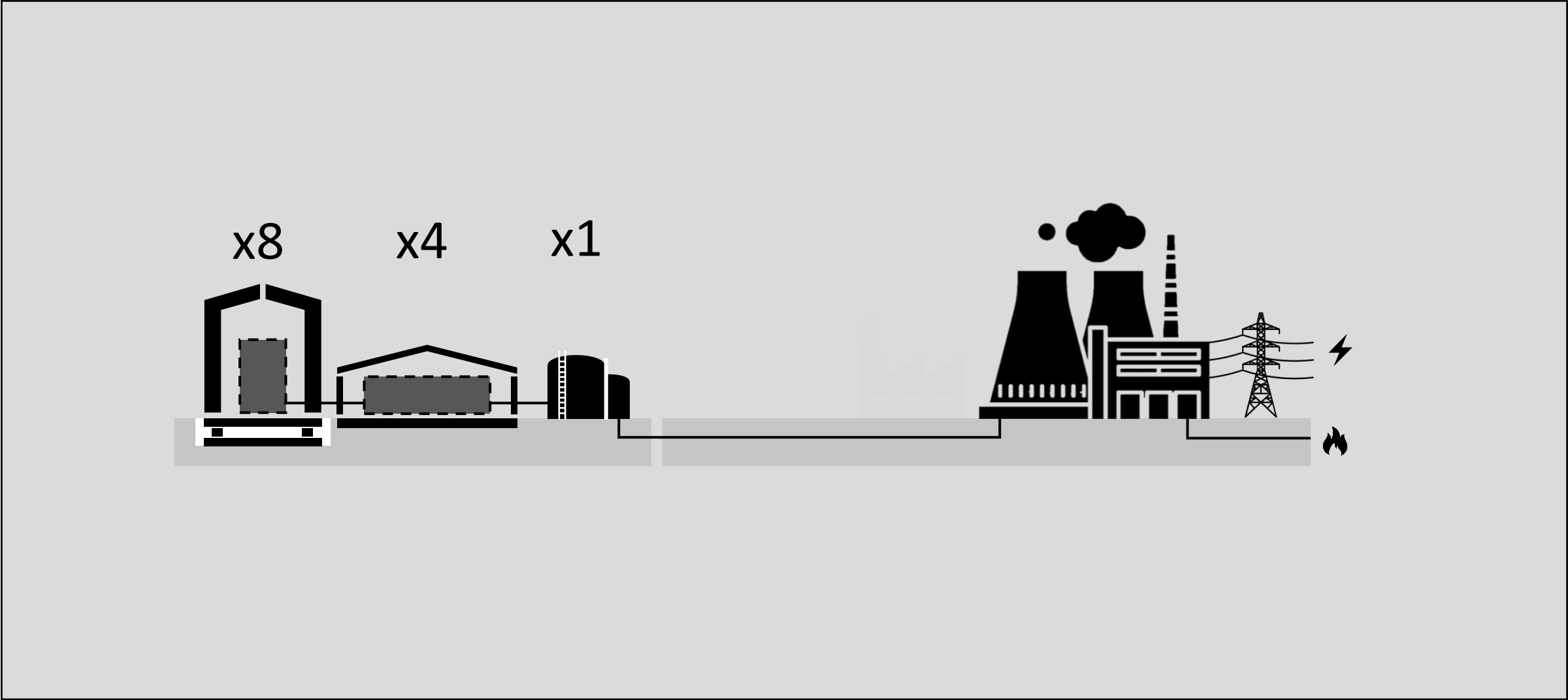
- Facilitate schedule certainty
- Facilitate fixed price bids
- Facilitate project-element scope detailing
- Facilitate supply-chain digital integration

4. Project Cost

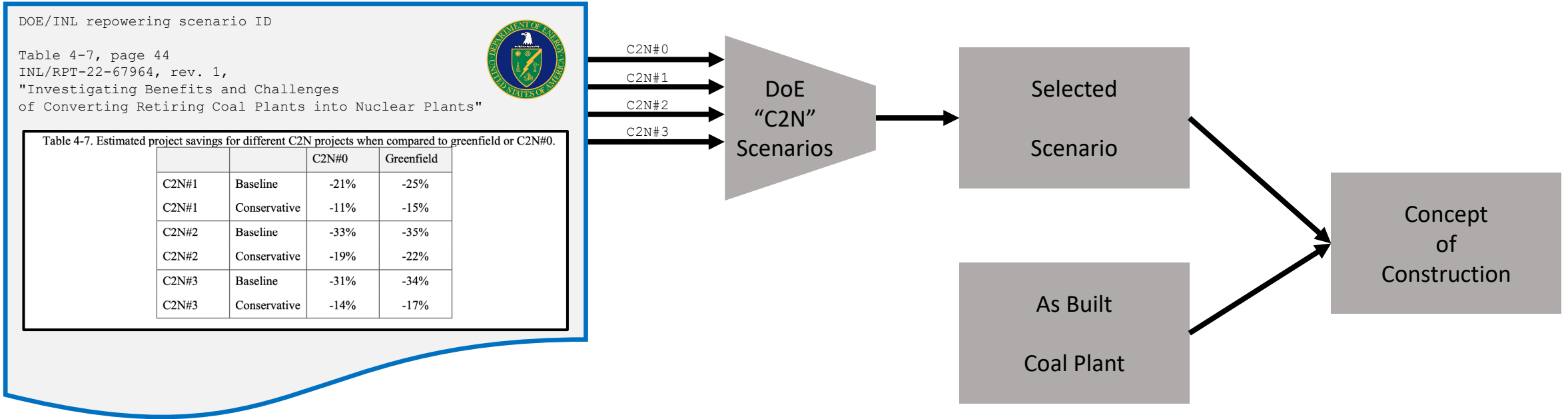
- Shorter project lowers financing cost
- Schedule confidence controls financing expenses
- Open supply-chain enhances market-based dynamics

Intent – Cost Certainty
Intent – Schedule Certainty

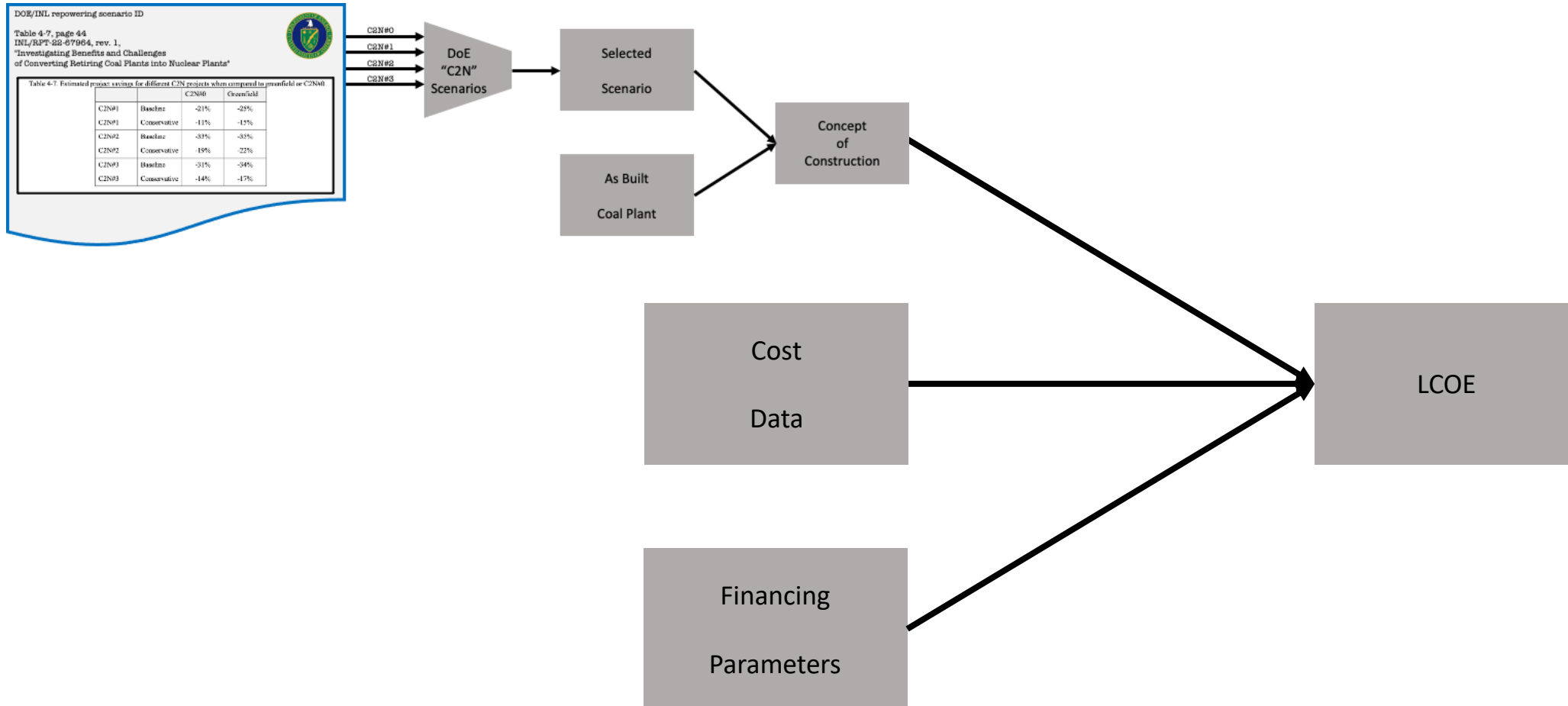
Form of “the answer” in repowering coal



Data flow



Data flow



Data flow



Data exchange by Excel

Cost

Data

Code_of_accounts example for ARPA-E deck 2023 05 31 - Saved to my Mac

Home Insert Draw Page Layout Formulas Data Review View Developer Tell me

Calibri (Body) 12

General

Currency 2 Normal 2 Normal 4

Normal Bad Good

AutoSum Fill Clear Sort & Filter

Account	Description	Refurbishment Category	Subject (C2Nddd01)	SMR 01	SMR 02	SMR 03	SMR 04	SMR 05	SMR 06	SMR 07	SMR 08	SMR 09	SMR 10
73	220A.269 Impurity monitoring	Unspecified											
74	220A.27 Instrumentation and Control	Unspecified											
75	220A.31 Support engineering	Unspecified											
76	220 Nuclear Steam Supply System (NSSS) sub-total	Subtotal											
77	221 Reactor equipment, Cooling Tank	Nuclear grade buildings	\$ 746,282	\$ 746,282	\$ 720,024	\$ 883,785	\$ 697,537	\$ 641,249	\$ 614,991	\$ 598,733	\$ 583,475	\$ 536,217	\$ 509,959
79	221 Reactor equipment, Decay Heat Condensers	Nuclear grade buildings	\$ 766,275	\$ 766,275	\$ 739,314	\$ 895,391	\$ 695,429	\$ 631,468	\$ 604,506	\$ 577,545	\$ 560,583	\$ 523,622	\$ 496,660
80	221 Reactor equipment, PMQD Grid	Nuclear grade buildings	\$ 13,086,198	\$ 13,086,198	\$ 12,625,798	\$ 12,165,318	\$ 11,704,877	\$ 11,244,437	\$ 10,783,997	\$ 10,323,556	\$ 9,863,116	\$ 9,402,676	\$ 8,942,235
81	221 Reactor equipment, Basement	Nuclear grade buildings	\$ 2,827,035	\$ 2,827,035	\$ 2,727,566	\$ 2,628,096	\$ 2,528,626	\$ 2,429,156	\$ 2,329,687	\$ 2,230,217	\$ 2,130,747	\$ 2,031,277	\$ 1,931,808
82	221 Reactor equipment, Can Silo Radtank	Nuclear grade buildings	\$ 7,580,919	\$ 7,580,919	\$ 7,314,183	\$ 7,047,447	\$ 6,780,711	\$ 6,513,975	\$ 6,247,239	\$ 5,980,503	\$ 5,713,767	\$ 5,447,030	\$ 5,180,294
83	221 Reactor equipment, Can Silo and Membrane Wall	Nuclear grade buildings	\$ 5,289,532	\$ 5,289,532	\$ 5,103,419	\$ 4,917,306	\$ 4,731,193	\$ 4,545,079	\$ 4,358,966	\$ 4,172,853	\$ 3,986,740	\$ 3,800,627	\$ 3,614,514
84	221 Reactor equipment, Fuel/Salt Drain Tank	Nuclear grade buildings	\$ 16,017,388	\$ 16,017,388	\$ 15,453,813	\$ 14,890,238	\$ 14,326,663	\$ 13,763,088	\$ 13,199,514	\$ 12,635,939	\$ 12,072,364	\$ 11,508,790	\$ 10,945,215
85	221 Reactor equipment, Offgas Holdup Tanks and Silos	Nuclear grade buildings	\$ 2,220,711	\$ 2,220,711	\$ 2,142,575	\$ 2,064,439	\$ 1,986,302	\$ 1,908,166	\$ 1,830,030	\$ 1,751,894	\$ 1,673,758	\$ 1,595,622	\$ 1,517,486
86	221 Reactor equipment, Fuel Cask and Fuel System	Nuclear grade buildings	\$ 3,719,763	\$ 3,719,763	\$ 3,598,902	\$ 3,478,041	\$ 3,357,180	\$ 3,196,258	\$ 3,035,337	\$ 2,874,415	\$ 2,713,493	\$ 2,552,571	\$ 2,391,650
87	221 Reactor equipment	Unspecified											
88	221 Reactor equipment	Unspecified											
89	222 Main heat transport system	Unspecified											
90	223 Safeguards system, shutdown cooling system	Unspecified											
91	224 Radwaste system	Unspecified											
92	225 Fuel handling	Unspecified											
93	226 Other reactor plant equipment, P/LP Motor	Unspecified											
94	226 Other reactor plant equipment, Secondary Loop Pump	Unspecified											
95	226 Other reactor plant equipment, Tertiary Loop Pump	Unspecified											
96	226 Other reactor plant equipment, Steam Generating Cell	Unspecified											
97	226 Other reactor plant equipment, Secondary Heat Exchangers	Unspecified											
98	226 Other reactor plant equipment, Tertiary Heat Exchangers	Heat Transport and Storage System (HTSS)	\$ 1,068,000	\$ 1,068,000	\$ 800,951	\$ 600,713	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560
99	227 Reactor instrumentation and control	Unspecified											
00	227 Reactor instrumentation and control	Unspecified											
01	228 Reactor plant miscellaneous items, electric system	Unspecified											
02	228 Reactor plant miscellaneous items	Unspecified											
03	22 Nuclear Heat Supply System	Subtotal	\$ 53,322,123	\$ 53,322,123	\$ 51,216,503	\$ 49,177,695	\$ 47,188,670	\$ 45,348,399	\$ 43,509,628	\$ 41,671,257	\$ 39,832,686	\$ 37,994,115	\$ 36,155,544
07	231 Turbine equipment	Turbines, Cooling and other existing plant	\$ 118,020,000	\$ 118,020,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
08	231 Turbine equipment	Unspecified											
09	231 Turbine equipment	Unspecified											
10	231 Generator equipment	Turbines, Cooling and other existing plant	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
11	231 Generator equipment	Unspecified											
12	231 Generator equipment	Unspecified											
13	233 Condensing Systems	Unspecified	\$ 17,218,000	\$ 17,218,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
14	234 Feed Heating Systems	Unspecified	\$ 75,732,000	\$ 75,732,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
15	235 Other turbine plant equipment	Unspecified											
16	235 Other turbine plant equipment, Cooling other	Advanced Heat Source (AHS) systems, safety gra	\$ 37,224,000	\$ 37,224,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
17	235 Other turbine plant equipment, Steam Piping	Advanced Heat Source (AHS) systems, safety gra	\$ 48,864,000	\$ 48,864,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
18	235 Other turbine plant equipment, Cooling other	Advanced Heat Source (AHS) systems, safety gra	\$ 37,224,000	\$ 37,224,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
19	235 Other turbine plant equipment	Advanced Heat Source (AHS) systems, safety gra											
20	235 Other turbine plant equipment	Unspecified											
21	236 Turbine Generator Equipment I&C	Unspecified	\$ 33,096,000	\$ 33,096,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
22	237 Turbine plant miscellaneous items	Unspecified											

Ready Accessibility: Investigate

Data exchange by Excel, **multiple reactors**

If you would like a copy of the latest version of this spreadsheet, send an email request to justin.aborn@terrapraxis.org

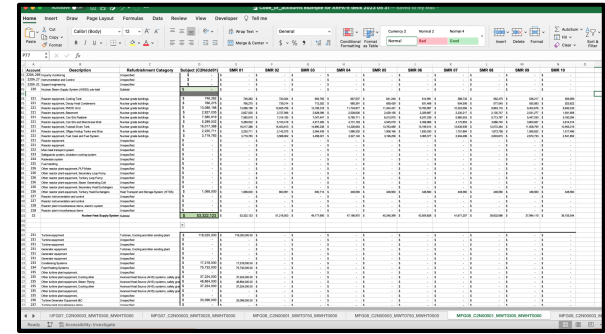
Account	Description	Refurbishment Category	Subject (C2Nddd01)	SMR 01	SMR 02	SMR 03	SMR 04	SMR 05	SMR 06	SMR 07	SMR 08	SMR 09	SMR 10
220A.269	Impurity monitoring	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
220A.27	Instrumentation and Control	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
220A.31	Support engineering	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
220	Nuclear Steam Supply System (NSSS) sub-total	Subtotal	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
221	Reactor equipment, Cooling Tank	Nuclear grade buildings	\$ 746,282	\$ 746,282	\$ 720,024	\$ 693,765	\$ 667,507	\$ 641,249	\$ 614,991	\$ 588,733	\$ 562,475	\$ 536,217	\$ 509,959
221	Reactor equipment, Decay Heat Condensers	Nuclear grade buildings	\$ 766,275	\$ 766,275	\$ 739,314	\$ 712,352	\$ 685,391	\$ 658,429	\$ 631,468	\$ 604,506	\$ 577,545	\$ 550,583	\$ 523,621
221	Reactor equipment, PMOD Grid	Nuclear grade buildings	\$ 13,086,198	\$ 13,086,198	\$ 12,625,758	\$ 12,165,318	\$ 11,704,877	\$ 11,244,437	\$ 10,783,997	\$ 10,323,556	\$ 9,863,116	\$ 9,402,676	\$ 8,942,235
221	Reactor equipment, Basement	Nuclear grade buildings	\$ 2,827,035	\$ 2,827,035	\$ 2,727,566	\$ 2,628,096	\$ 2,528,626	\$ 2,429,156	\$ 2,329,687	\$ 2,230,217	\$ 2,130,747	\$ 2,031,277	\$ 1,931,808
221	Reactor equipment, Can Silo Radtank	Nuclear grade buildings	\$ 7,580,919	\$ 7,580,919	\$ 7,314,183	\$ 7,047,447	\$ 6,780,711	\$ 6,513,975	\$ 6,247,239	\$ 5,980,503	\$ 5,713,767	\$ 5,447,030	\$ 5,180,294
221	Reactor equipment, Can Silo and Membrane Wall	Nuclear grade buildings	\$ 5,289,532	\$ 5,289,532	\$ 5,103,419	\$ 4,917,306	\$ 4,731,193	\$ 4,545,079	\$ 4,358,966	\$ 4,172,853	\$ 3,986,740	\$ 3,800,627	\$ 3,614,514
221	Reactor equipment, Fuel Salt Drain Tank	Nuclear grade buildings	\$ 16,017,388	\$ 16,017,388	\$ 15,453,813	\$ 14,890,238	\$ 14,326,663	\$ 13,763,088	\$ 13,199,513	\$ 12,635,938	\$ 12,072,363	\$ 11,508,788	\$ 10,945,213
221	Reactor equipment, Offgas Holdup Tanks and Silos	Nuclear grade buildings	\$ 2,220,711	\$ 2,220,711	\$ 2,142,575	\$ 2,064,439	\$ 1,986,302	\$ 1,908,166	\$ 1,830,030	\$ 1,751,894	\$ 1,673,758	\$ 1,595,622	\$ 1,517,486
221	Reactor equipment, Fuel Cask and Fuel System	Nuclear grade buildings	\$ 3,719,783	\$ 3,719,783	\$ 3,588,802	\$ 3,458,821	\$ 3,327,840	\$ 3,196,859	\$ 3,065,877	\$ 2,934,896	\$ 2,803,915	\$ 2,672,934	\$ 2,541,953
221	Reactor equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
221	Reactor equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
222	Main heat transport system	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
223	Safeguards system, shutdown cooling system	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
224	Radwaste system	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
225	Fuel handling	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
226	Other reactor plant equipment, PUP Motor	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
226	Other reactor plant equipment, Secondary Loop Pump	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
226	Other reactor plant equipment, Tertiary Loop Pump	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
226	Other reactor plant equipment, Steam Generating Call	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
226	Other reactor plant equipment, Secondary Heat Exchangers	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
226	Other reactor plant equipment, Tertiary Heat Exchangers	Heat Transport and Storage System (HTSS)	\$ 1,068,000	\$ 1,068,000	\$ 800,951	\$ 600,713	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560	\$ 448,560
227	Reactor instrumentation and control	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
227	Reactor instrumentation and control	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
228	Reactor plant miscellaneous items, electric system	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
228	Reactor plant miscellaneous items	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
22	Nuclear Heat Supply System	Subtotal	\$ 53,322,123	\$ 53,322,123	\$ 51,216,503	\$ 49,177,895	\$ 47,139,287	\$ 45,094,679	\$ 43,050,071	\$ 41,005,463	\$ 38,960,855	\$ 36,916,247	\$ 34,871,639
231	Turbine equipment	Turbines, Cooling and other existing plant	\$ 118,020,000	\$ 118,020,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
231	Turbine equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
231	Turbine equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
231	Generator equipment	Turbines, Cooling and other existing plant	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
231	Generator equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
231	Generator equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
233	Condensing Systems	Unspecified	\$ 17,218,000	\$ 17,218,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
234	Feed Heating Systems	Unspecified	\$ 75,732,000	\$ 75,732,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
235	Other turbine plant equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
235	Other turbine plant equipment, Cooling other	Advanced Heat Source (AHS) systems, safety gra	\$ 37,224,000	\$ 37,224,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
235	Other turbine plant equipment, Steam Piping	Advanced Heat Source (AHS) systems, safety gra	\$ 48,864,000	\$ 48,864,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
235	Other turbine plant equipment, Cooling other	Advanced Heat Source (AHS) systems, safety gra	\$ 37,224,000	\$ 37,224,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
235	Other turbine plant equipment	Advanced Heat Source (AHS) systems, safety gra	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
235	Other turbine plant equipment	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
236	Turbine Generator Equipment I&C	Unspecified	\$ 33,096,000	\$ 33,096,000	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
237	Turbine plant miscellaneous items	Unspecified	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -

Gen IV
Standard*
Code of
Accounts

* Gen-IV International Forum (<https://www.gen-4.org>)
2007, "Cost Estimating Guidelines for Generation IV Nuclear Energy Systems"
https://www.gen-4.org/gif/upload/docs/application/pdf/2013-09/emwg_guidelines.pdf



Data exchange by Excel, standard text strings



The image shows a screenshot of an Excel spreadsheet. The spreadsheet contains a large table with multiple columns and rows. The columns are labeled with various reactor parameters, including 'Reactor ID', 'Manufacturer', 'Repowering scenario', 'DoE/INL ID', 'Reactor thermal power (MWt)', and 'Thermal storage (MWht)'. The data is organized into several sections, with some rows highlighted in green. The spreadsheet is displayed in a window with a standard Windows interface.

MFGdd

Reactor manufacturer ID

C2Nddd["00" / "01" / "02" / "03"] Repowering scenario

DoE/INL ID

MWTdddd

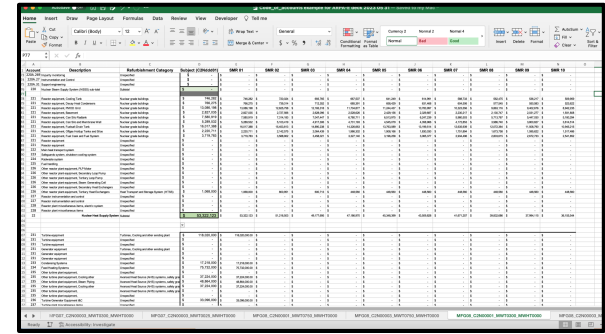
Reactor thermal power (MWt)

MWHTdddd

Thermal storage (MWht)

Data exchange by Excel

Worksheet-naming examples



MFG07_C2N0000**00**_MWT0300_MWHT0000

DoE/INL scenario 0

MFG07_C2N0000**01**_MWT0300_MWHT0000

DoE/INL scenario 1

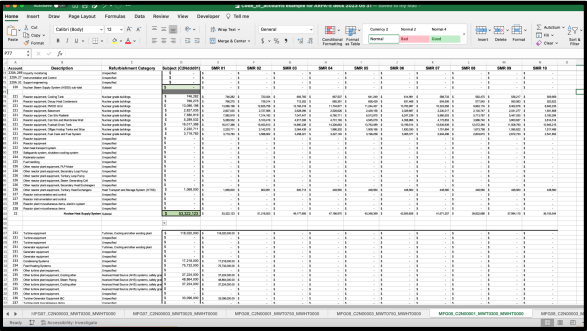
MFG07_C2N0000**02**_MWT0300_MWHT0000

DoE/INL scenario 2

MFG07_C2N0000**03**_MWT0300_MWHT0000

DoE/INL scenario 3

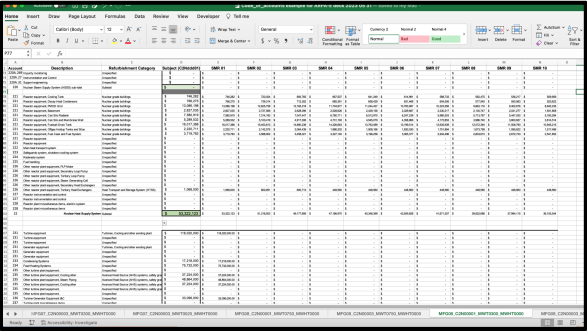
Standard text strings, extensibility



- MFGdd Reactor manufacturer ID
- OWNdd Owner ID
- EPCdd Engineering, Procurement, and Construction ID
- VNDdd Vendor ID
- REGdd Regulator ID
- RCHdd Researcher ID

Augmented Backus–Naur form (ABNF)
https://en.wikipedia.org/wiki/Augmented_Backus%E2%80%93Naur_form
"d" = single DIGIT: %x30–39 Decimal digits (0–9)

Standard text strings, thermal power examples



The image shows a screenshot of a spreadsheet application, likely Microsoft Excel, displaying a large table of data. The table has multiple columns, with some headers in bold and some cells containing numerical values. The data appears to be organized into sections, possibly representing different thermal power examples or components. The spreadsheet is viewed in a windowed environment with a standard menu bar and toolbar.

MWT0025

25 Megawatt thermal interface element

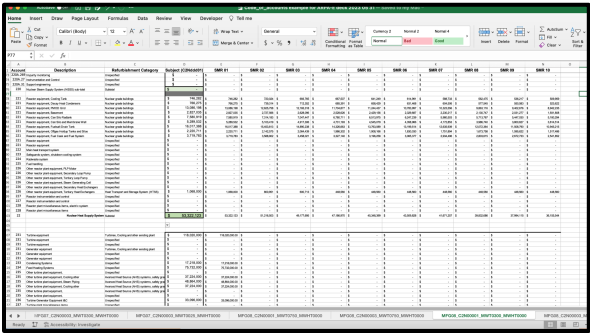
MWT0300

300 Megawatt thermal interface element

MWT0789

789 Megawatt thermal interface element

Standard text strings, thermal storage examples



The screenshot shows a software interface with a menu bar (File, Edit, Page Layout, Formulas, Data, Window, View, Developer, Help) and a ribbon with various tool icons. Below the ribbon is a large data table with multiple columns and rows. The table contains numerical data and text labels, possibly representing simulation results or material properties. The interface also includes a status bar at the bottom.

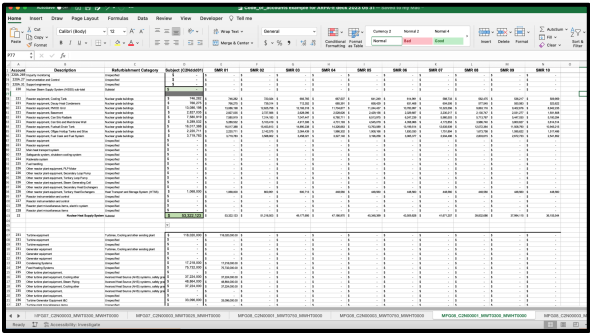
MWHT0000

Element with no integrated thermal storage

MWHT0123
storage

Element that integrates 123 MWht of thermal

Today : ARPA-E “nuclear heat” workshop



MFGdd

Reactor manufacturer ID

C2Nddd["00" / "01" / "02" / "03" / "99"]

Repowering

scenario DoE/INL ID

Heat-Only scenario ?

MWTdddd
(MWt)

Reactor thermal power

Thermal storage (MWh)

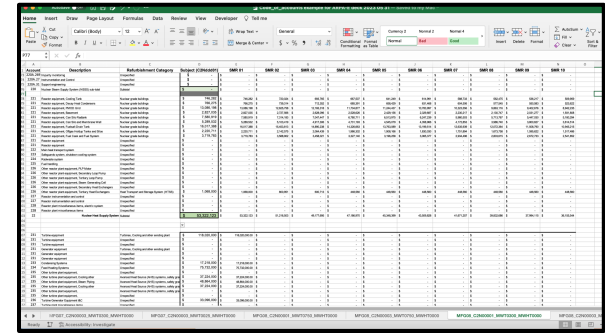
TERRA
PRAXIS

Augmented Backus–Naur form (ABNF)
https://en.wikipedia.org/wiki/Augmented_Backus%E2%80%93Naur_form
"d" = single DIGIT: %x30–39 Decimal digits (0–9)

Data exchange by Excel

Worksheet-naming example

Heat-only reactor scenario



The screenshot shows an Excel spreadsheet with a complex table structure. The table has multiple columns, including 'Subcategory', 'Category', 'Description', and several columns for cost values (e.g., 'Cost', 'Unit Cost', 'Total Cost'). The data is organized into several sections, with some rows highlighted in green. The spreadsheet appears to be a detailed cost breakdown for a reactor scenario.

MFG07_C2N00099_MWT0300_MWHT0000

Cost assessment for:

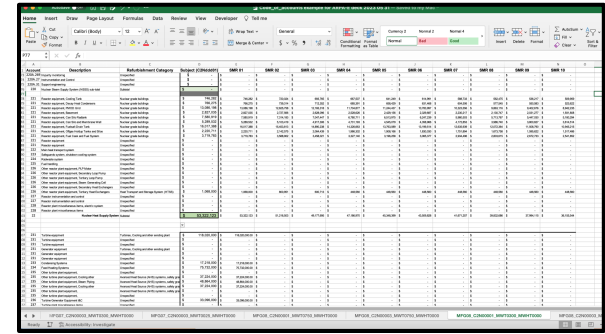
Reactor manufacturer 07's

300 MWt reactor (with no integrated TES)

Applied to a "non-coal" heat only application

Data exchange by Excel

Example of a “thermal storage only” element



The image shows a screenshot of an Excel spreadsheet. The spreadsheet contains a large table with many columns and rows. The columns are labeled with various codes and numbers, and the rows contain numerical data. The spreadsheet is displayed in a window with a standard menu bar and toolbar.

Non-Reactor Vendor



VND05_C2N00099_MWT0012_MWHT0034

Thermal storage only element, with:

12 Mwt thermal power interface

34 MWht thermal storage capacity

Proposed reserved scenario number, "heat"

