Impact of advanced manufacturing and materials on fusion power plant costs

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Acknowledge support from ARPA-E BETHE Program. Work at Woodruff Scientific performed under Purchase Order PO230181-Y

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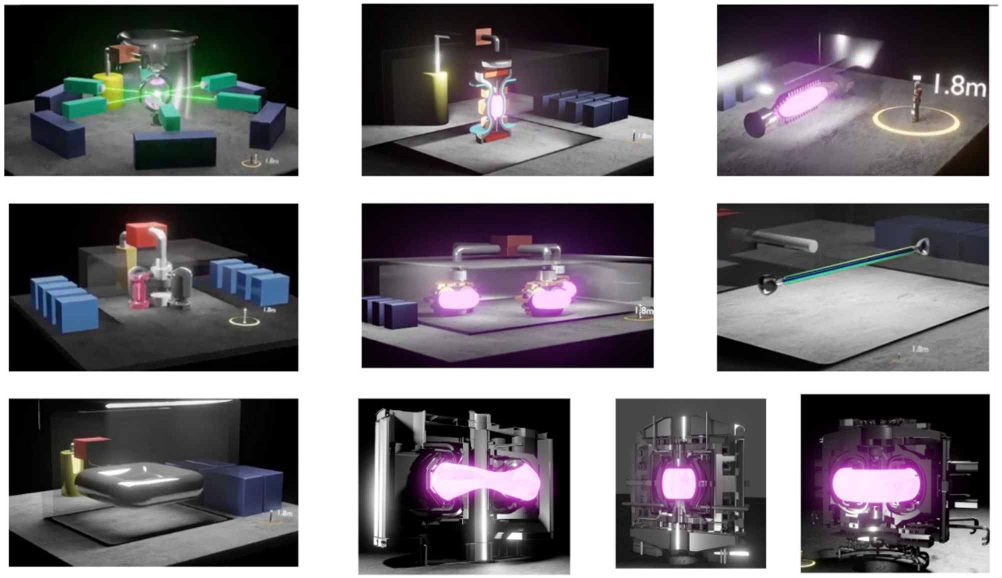
Outline

- Background and what influences the discussion
- Methods for costing
- Example 1: Advanced materials
- Example 2: Additive manufacturing
- Example 3: Workflow automation
- Discussion
- Summary

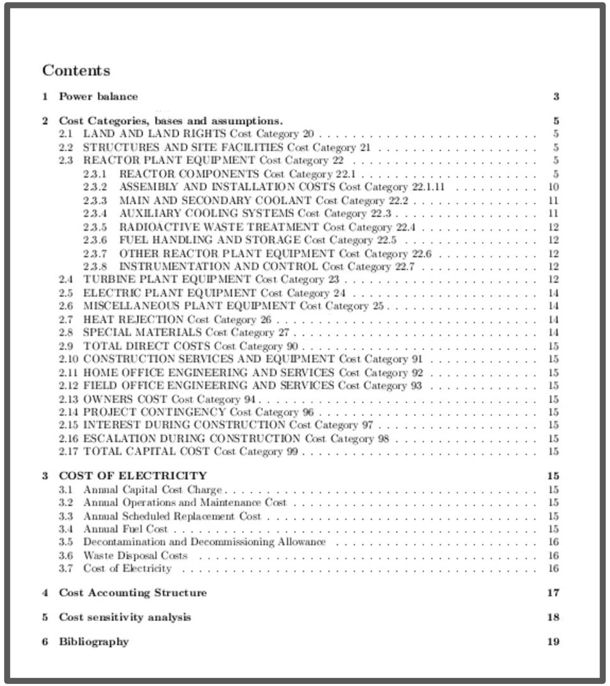
All fusion concepts under ARPA-E

- We are building on **Woodruff**'s 2017 Study (with Bechtel), 2019 Study (with Lucid Catalyst) and 2021 Study (extension to all ARPA-E supported teams) [1]
- Developed a '**standardized costing approach**' and worked with international partners

We have performed cost analysis for all the systems depicted - supported by US DOE



Our costing reports are now auto-generated



Contents

[1] https://arpa-e.energy.gov/sites/default/files/2020-09/Day2_1535_WS_Woodruff.pdf; https://arpa-e.energy.gov/sites/default/files/2022-05/330_Zarnstorff.pdf

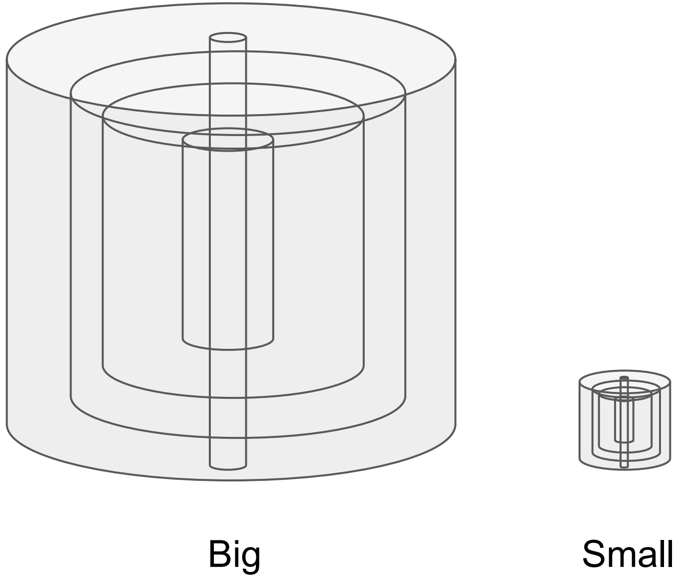
Costing 101

- Total Capital Cost (TCC) of power core:

$$TCC = \sum_i M_i \times C_i \times f_M$$

Where M_i is the mass of the subassy in kg and C_i is a cost per kg of the subassy and f_M is the manufacturing factor, and the summation occurs over the entire assy.

- 1000 tonnes, $10Bn
- 1-10 tonnes, $10-100M



Costing 101

$$LCOE=(C_{AC}+(C_{OM}+C_{SCR}+C_{CF})*(1+y)^{Y})/(8760*P_{E}*p_{f})+C_{DD}$$

Where C_{AC} [$/yr] is the annual capital cost charge (entailing the total capital cost of the plant), C_{OM} [$/yr] is the annual operations and maintenance cost, C_{SCR} [$/yr] is the annual scheduled component replacement costs, C_{F} [$/yr] is the annual fuel costs, y is the annual fractional increase in costs due to inflation over the expected lifetime of the plant Y [years], P_{E} [MWe] is the electric power of the plant, p_{f} is the plant availability (typically 0.6-0.9) and C_{DD} [mill/kWh] is the decontamination and decommissioning allowance.

Costing 101 impact of materials

$$LCOE=(C_{AC}+(C_{OM}+C_{SCR}+C_{CF})*(1+y)^Y)/(8760*P_E*p_f)+C_{DD}$$

Where C_{AC} [$/yr] is the annual capital cost charge (entailing the total capital cost of the plant), C_{OM} [$/yr] is the annual operations and maintenance cost, C_{SCR} [$/yr] is the annual scheduled component replacement costs, C_F [$/yr] is the annual fuel costs, y is the annual fractional increase in costs due to inflation over the expected lifetime of the plant Y [years], P_E [MWe] is the electric power of the plant, p_f is the plant availability (typically 0.6-0.9) and C_{DD} [mill/kWh] is the decontamination and decommissioning allowance.

Capital cost

Maintenance

Scheduled replacement cost - mttf

Availability impacted by the maintenance, need to consider RAMIs

Activated components will increase this cost!

Example 1: Advanced materials impact C_{AC}, C_{SCR}, p_f and C_{DD}

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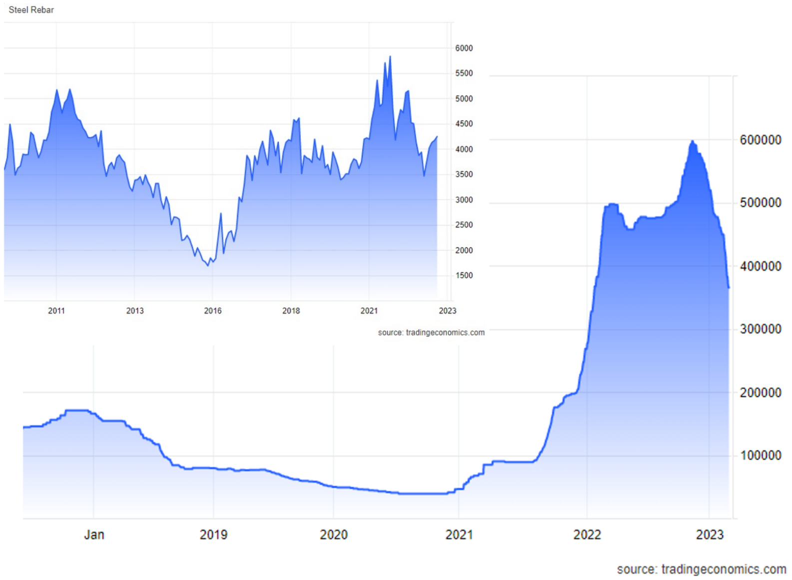
Lower cost materials lower C_{AC} and C_{SCR} thereby also LCOE

Example: Materials costs are not linked to inflation, and can be volatile →

Reliability increases availability therefore lowers LCOE

Example: Austenitic stainless steels are highly resistant to creep at high temperatures, due to their high chromium and nickel content.

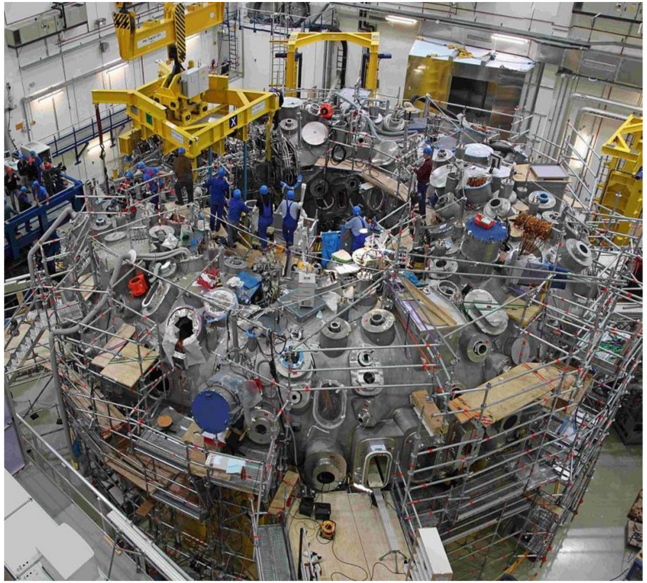


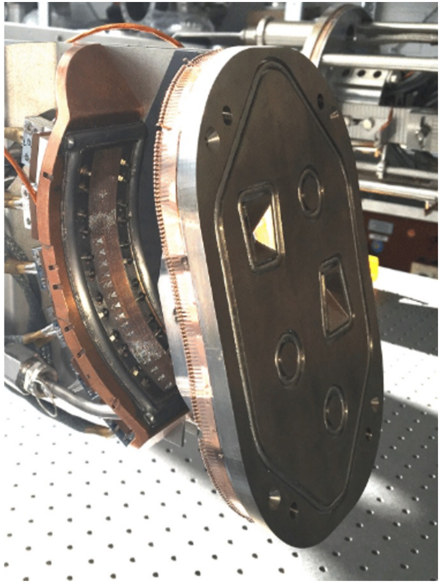
After subsidizing battery manufacturers and granting cash rewards to new electric vehicle purchases, the Chinese government halted incentives for the new energy auto sector in January and catalyzed a decline in demand.

https://tradingeconomics.com/commodity/lithium

Example 2: Additive manufacturing impacts M and f_M

~70% overall cost reduction in the fabrication relative to components that are conventionally manufactured (e.g. drill, mill and weld).





CALC4XL costs

Conventional manufacture:
$50000, labor: 35% materials: 65%

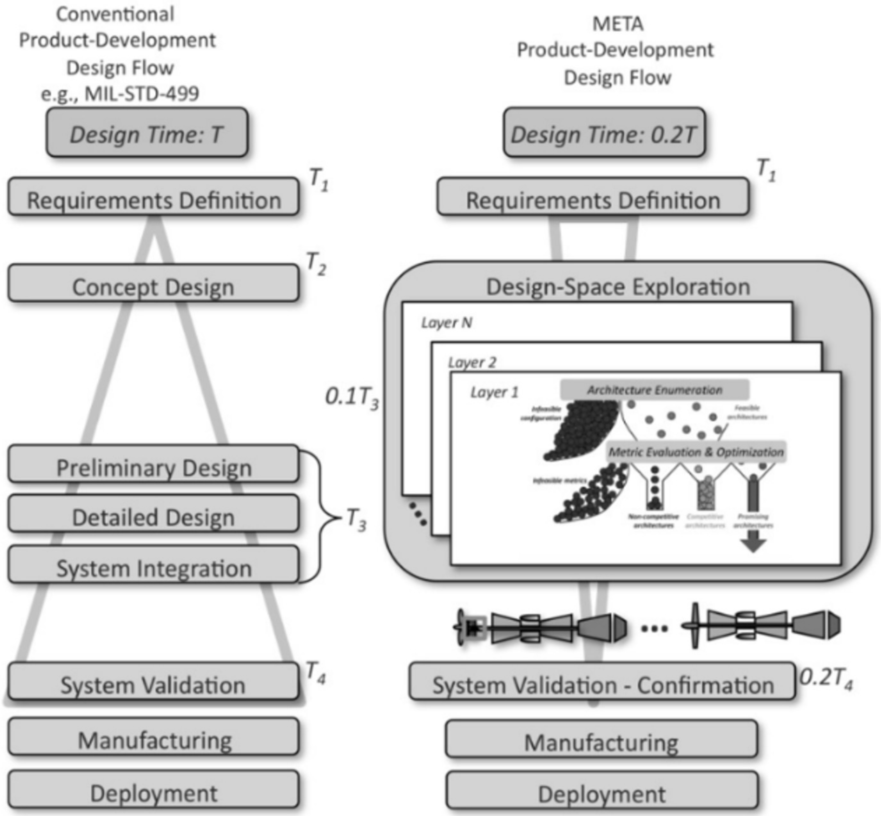
Additive manufacturing:
$15000 labor: 5% materials: 95%

Time to recover sunk costs from retooling: 5-7 years.

Example 3: Workflow tools

~40% cost reduction in the design stages of a system consisting of multiple subsystems [1].

Digital twins or ‘simulators’ also included in GENIV costing since 2007.



De Weck, Olivier L. “Feasibility of a 5x Speedup in System Development Due to META Design.” Volume 2: 32nd Computers and Information in Engineering Conference, Parts A and B (August 12, 2012). https://dspace.mit.edu/bitstream/handle/1721.1/116271/1105_1.pdf?sequence=1&isAllowed=y

Discussion - impact on power plant cost

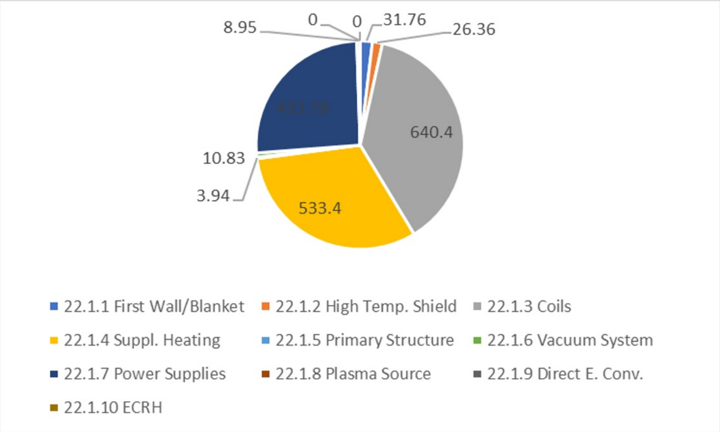
(an anonymous tokamak example!)

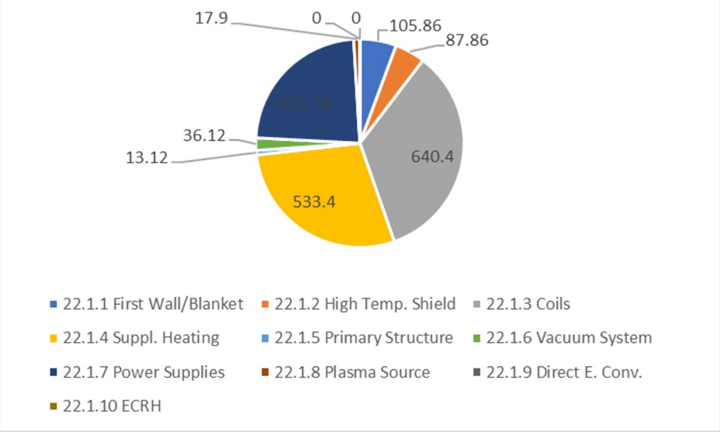
Overall, cost savings through AM and advanced materials could be as large as 70%, if we are able to capture these cost savings in major components, we can reduce **TCC** by 7% or >100M USD.

→possible to consider more subsystems → >10%.

Impact on **LCOE** is larger if we can use reduced activation materials, and components require less frequent replacement, so 6.9 c/kWh reduces to 5.7 c/kWh, a 17% reduction.

→possible to optimize → >20% reduction.





Summary

Background: ARPA-E fusion costing studies since 2017

Methods for costing: TCC, LCOE, bottoms up

Example 1: advanced materials (impacts on all cost elements)

Example 2: additive manufacturing - costs dramatically impacted (70%)

Example 3: workflow automation and collaboration (50%)

Discussion: impacts on TCC >10%, on LCOE >20% for new materials and manufacturing, possible, need to consider case-by-case