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Advanced Ultrasupercritical Update

Rankine Cycles above 1200ºF

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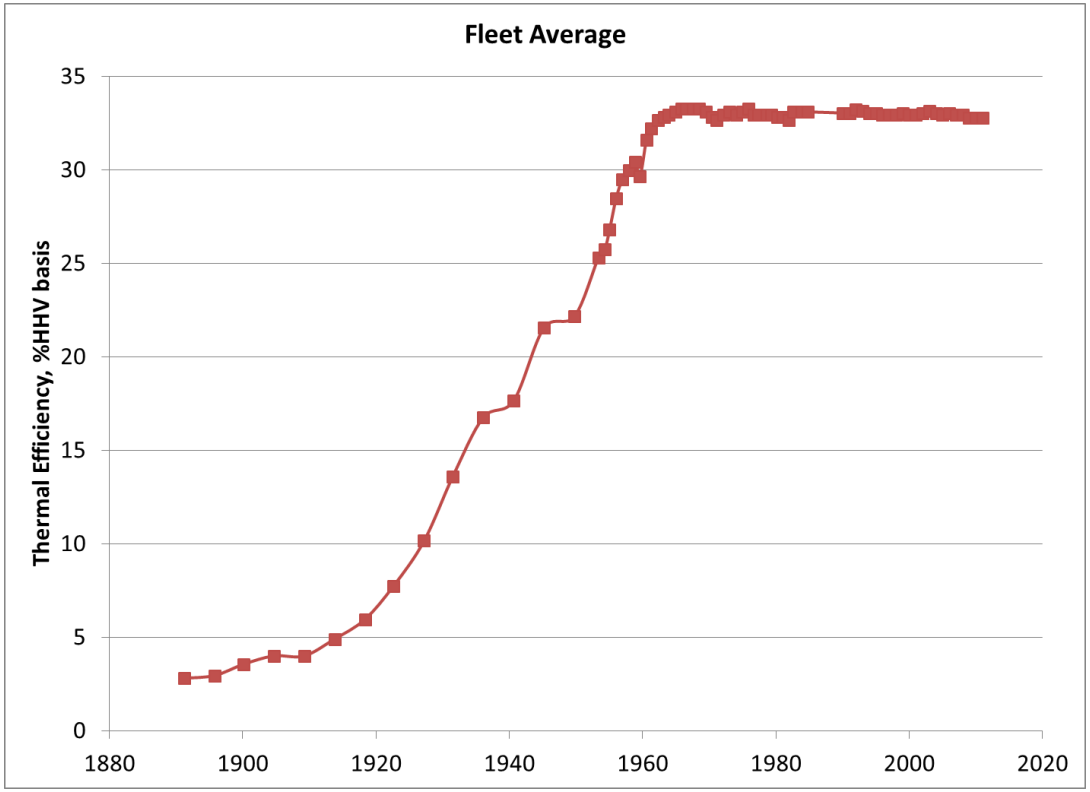
It's All About Thermal Efficiency

- According to Sadi Carnot
  - Thermal Efficiency = $1 - T_L/T_H$
- To get higher efficiencies, we must minimize the value of T_L/T_H
- We cannot do much to reduce T_L, but we can increase T_H by operating at higher temperatures

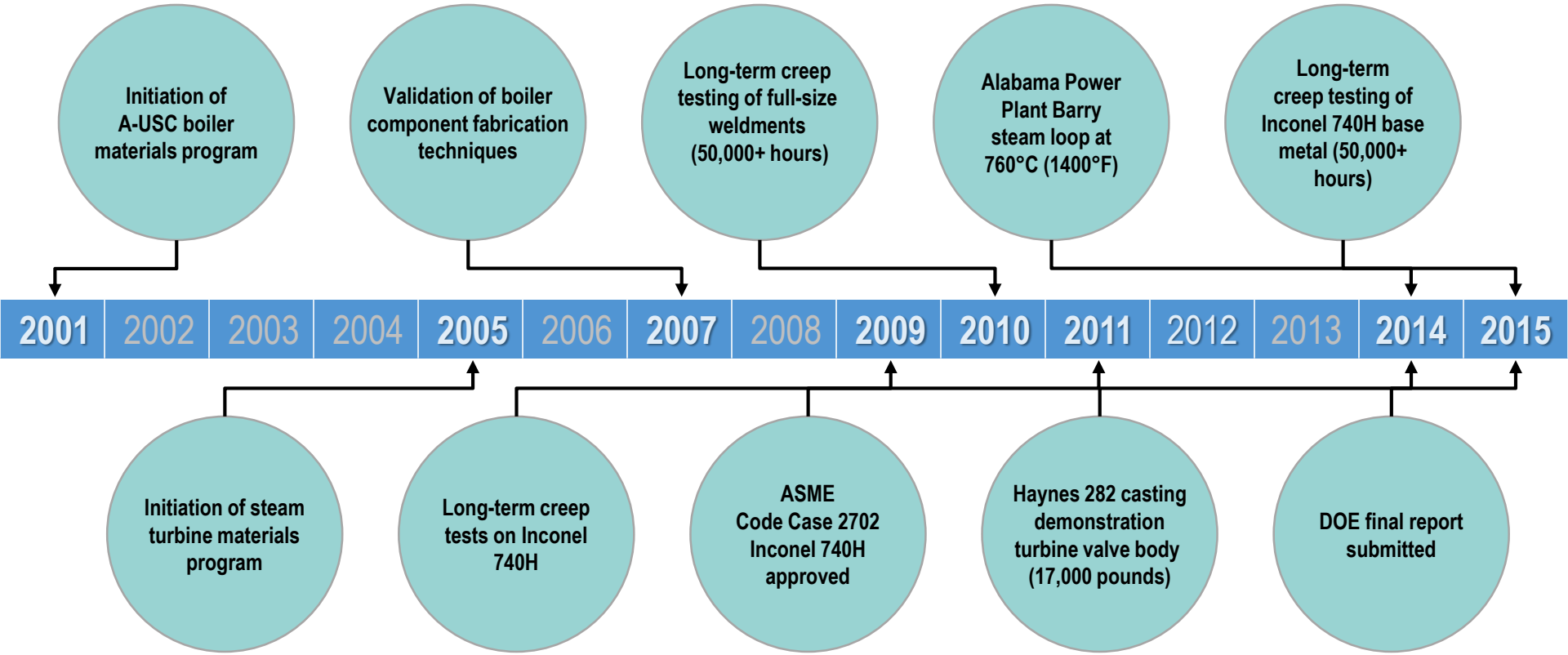
http://www.wikiwand.com/fr/Sadi_Carnot_(physicien)

US Coal Power Plant Thermal Efficiency Through the Years



- Efficiency grew significantly and rapidly from 1920 to 1960
- Has plateaued since 1960s
- Steam turbine inlet temperatures rose from 600ºF (315ºC) in 1920 to between 1000º and 1100ºF (538º and 600ºC) in the 1960s
- Moving beyond today's efficiency level will require moving beyond ferritic steels

14-year DOE-Ohio AUSC Materials Program



Recent Results: In-Plant Testing at 760°C (1400°F) Operating Steam Corrosion Test Loop

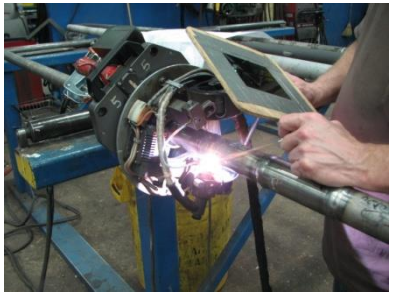
- Phase 1
  - Extensive laboratory testing &air-cooled probes in boiler
  - Steam-cooled loop (high S coal)
- 2nd Steam Loop
  - **World's first steam loop operating at 760°C (1400°F)**
  - **Removed from service after 33months with >16,000hrs in operation**
  - **Evaluations = little to no wastage**

Materials include:

740H, CCA617, HR6W, Super 304H, Coating, Overlays, and Others

Fabrication in Alstom Chattanooga TN shop

Prior to Welding

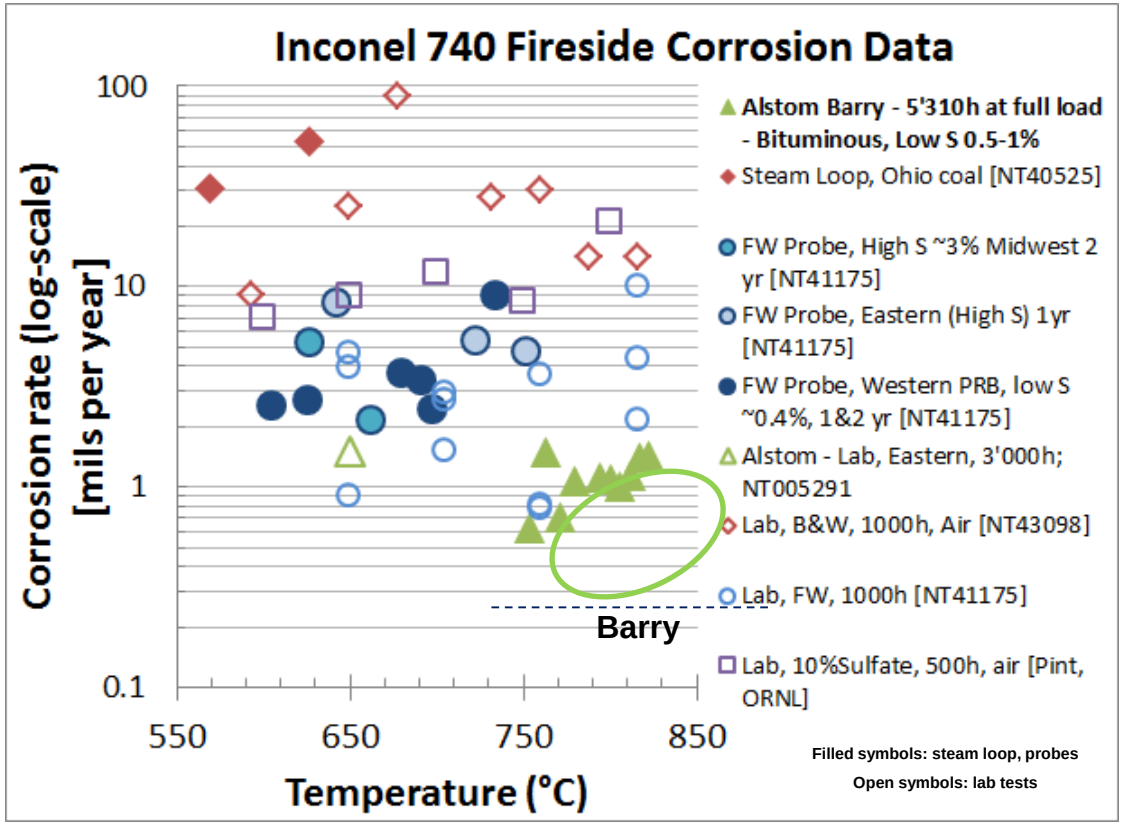


Being Welded

After Assembly

Conclusions – Fireside corrosion of IN740

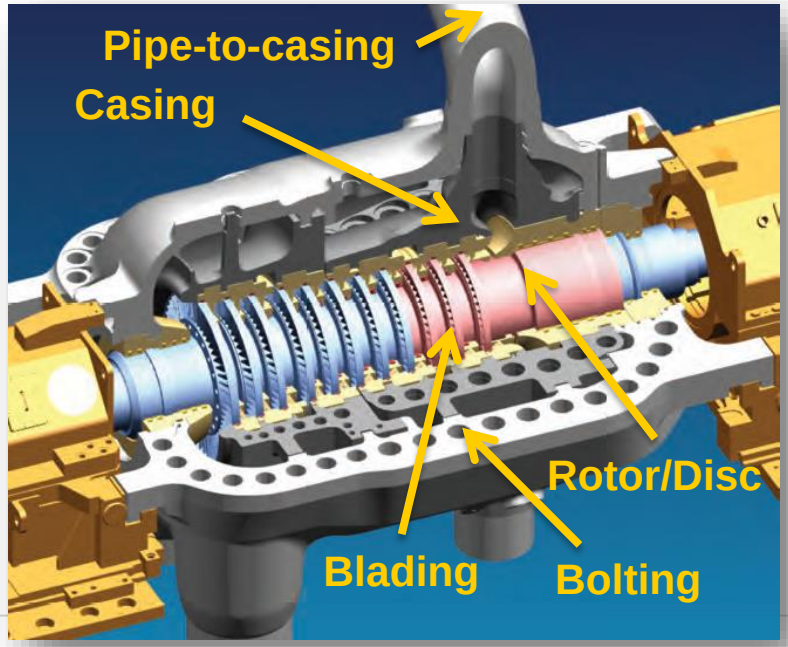
- In general, the depth of attack at Barry seems to be smaller than those in previously tested steam loops & probes in other boilers
  - Lower-sulfur coal used at Plant Barry is benign
- Corrosion rates from lab tests are varying over a wide range (>1 order of magnitude)
- Corrosion rates from recent Alstom testing (green triangles) are close to corrosion rates experienced in Barry Steam Loop



DOE/OCDO A-USC Steam Turbine Consortium

- Selected Materials from Phase I
- Rotor/Disc Testing (full-size forgings)
- Blade/Bucket Alloy Testing
- Cast Casing Scale-Up Alloy Testing
- Casing Welding and Repair
- A-USC Economics

1400°F (760°C) Steam Turbine Conceptual Design (HP) – *Bolted Construction*



U.S. DEPARTMENT OF ENERGY

Ohio Coal Development Office

OAK RIDGE NATIONAL LABORATORY
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GE Energy

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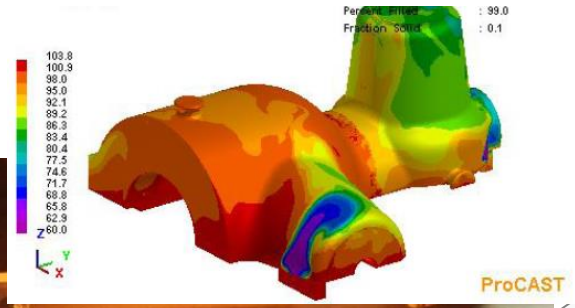
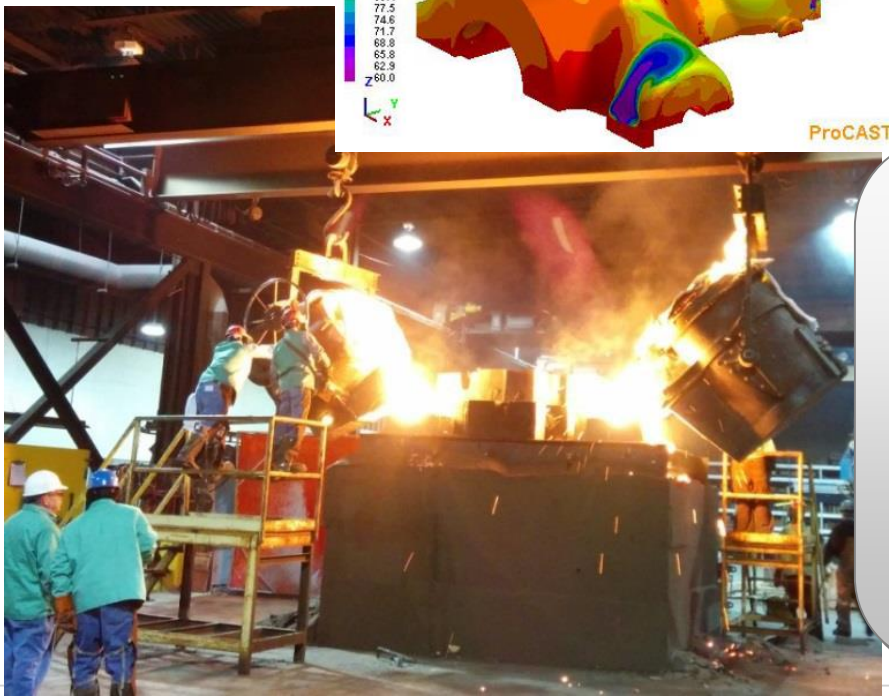
Energy Industries Of Ohio

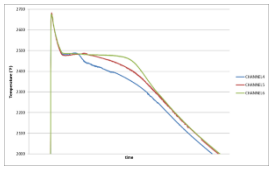
NETL

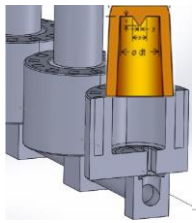
Modeling and Large-Scale Casting Development

- Casting simulation developed
- Cooling rate and secondary dendrite arm spacing predictions validated
- Modeling used to design valve body casting









~2700kg (6,000lb)
½ Valve body

(simulate full-size valve)

Casting successful
Nov. 2014 (17,500lb pour)

Haynes 282 Steam Turbine Valve Casing

- **Large Casting Material Evaluation Test Results**

•Worlds first large Haynes 282 casting with poured weight 17000 lbs.

•Casting wall thicknesses range 3.5 to 8 inches

•SDAS values in the range of 215µ to 275µ

•Met VT, RT and LPT, NDT Inspection and acceptance criteria

•Chemical analysis, tensile, LCF, stress rupture, Charpy and fracture toughness test results of cast on coupons, trepan and chilled cast sections were summarized

Summary: US DOE/OCDO A-USC Consortium

- **Unprecedented success in developing the materials technology to enable A-USC Steam cycles up to 760°C (1400F)**
  - Extensive laboratory and shop R&D
  - Field applications for fireside corrosion
- **Future for these materials:**
  - A-USC steam cycles (enables economic oxy-combustion, post-combustion capture, etc.)
  - Supercritical CO_2 cycles (need >700°C for efficiency)
  - Existing plant retrofits to improve efficiency and reduce CO_2

USC vs A-USC Performance & Cost Comparisons

	USC Plant		A-USC Plant	
	without PCC	With PCC	without PCC	With PCC
Main and Reheat Steam Temperature, ^oF	1100/1100	1100/1100	1350/1400	1350/1400
CO_2 Emissions lb/MWh-gross	1758	1400	1592	1400
Net Power Output, MW	749.6	709.0	754.2	734.3
Net Efficiency, % (HHV)	38.8	36.7	41.4	40.3
% of Flue Gas to Capture	0	24	0	15
Total Plant Cost, $/kW	2,637	**3,306**	2,933	**3,190**
LCOE, $/MWh (including CO_2 T&S cost)	80.0	**98.9**	84.7	**93.3**
Cost of CO_2 Avoided, $/tonne (relative to USC w/o PCC)		124	84	96

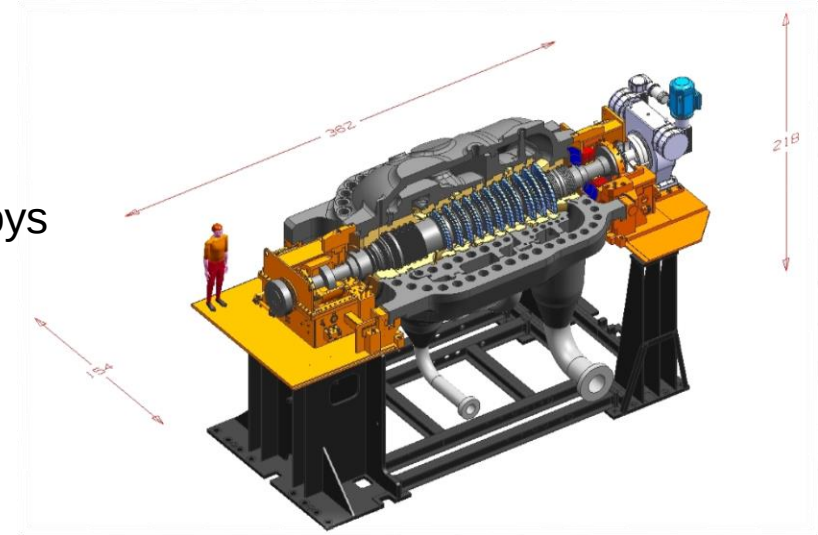
Both plants firing Powder River Basin sub-bituminous coal

USC at 1400 lb CO_2/MWhr extrapolated from DOE/NETL-2015/1720 results

Estimate $5/MWh advantage for A-USC at 1400 lb CO_2/MWhr

The Next Step: AUSC ComTest (Component Test)

- Boiler: Design, install, start-up, operate and **cycle** high temperature nickel components (740H & others)
  - Large diameter piping (commercial-scale)
  - Header and tubes
  - Superheater materials exposure
- Turbine: Design, install, start-up, operate and cycle 760°C (1400°F) 8 MW steam turbine & **full size** steam valves
  - Materials & coatings
  - Turbine architecture
  - Oxidation, deposits, SPE
  - NDE/NDT
- Fabrication methods & supply chain for super-alloys



Proposed ComTest Steam Turbine

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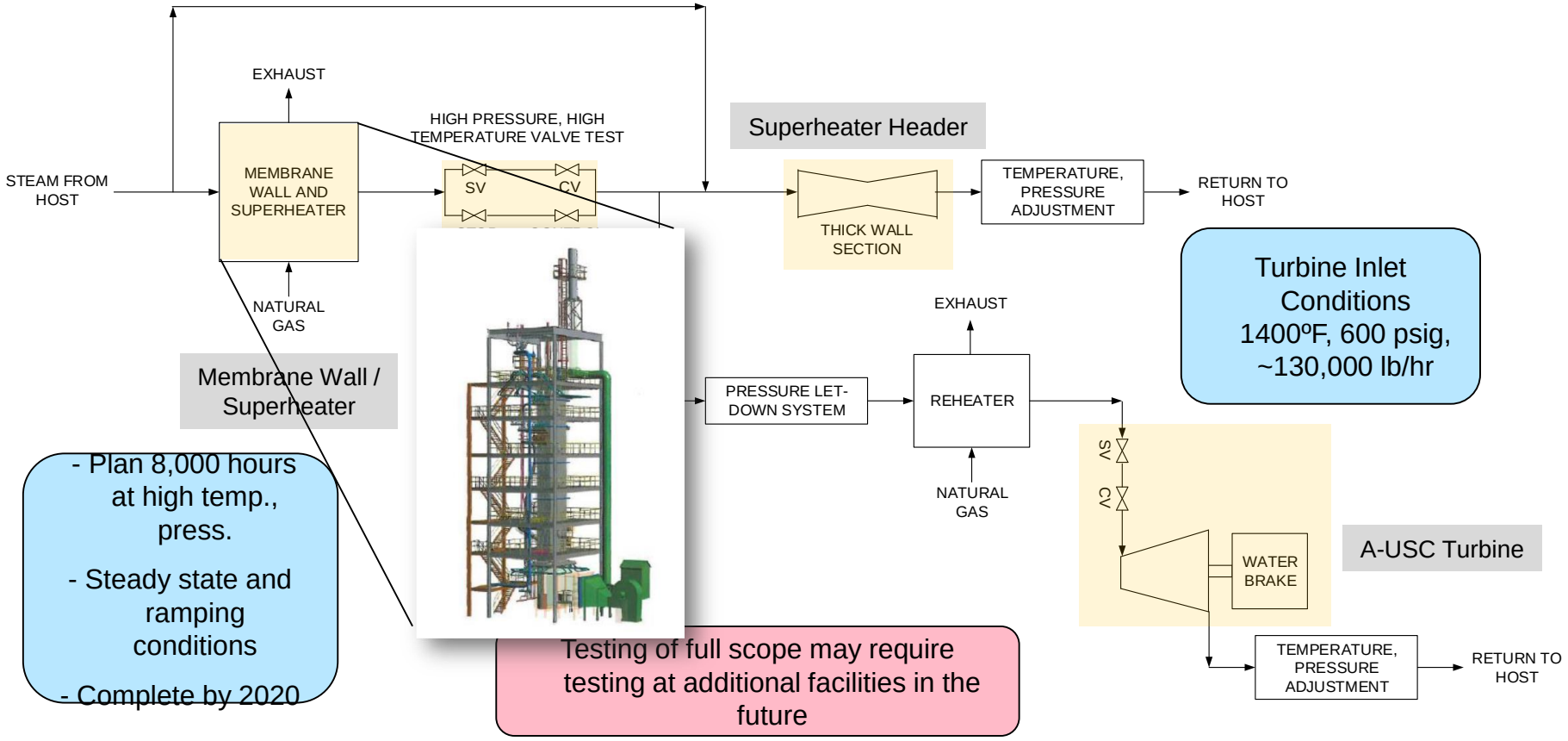
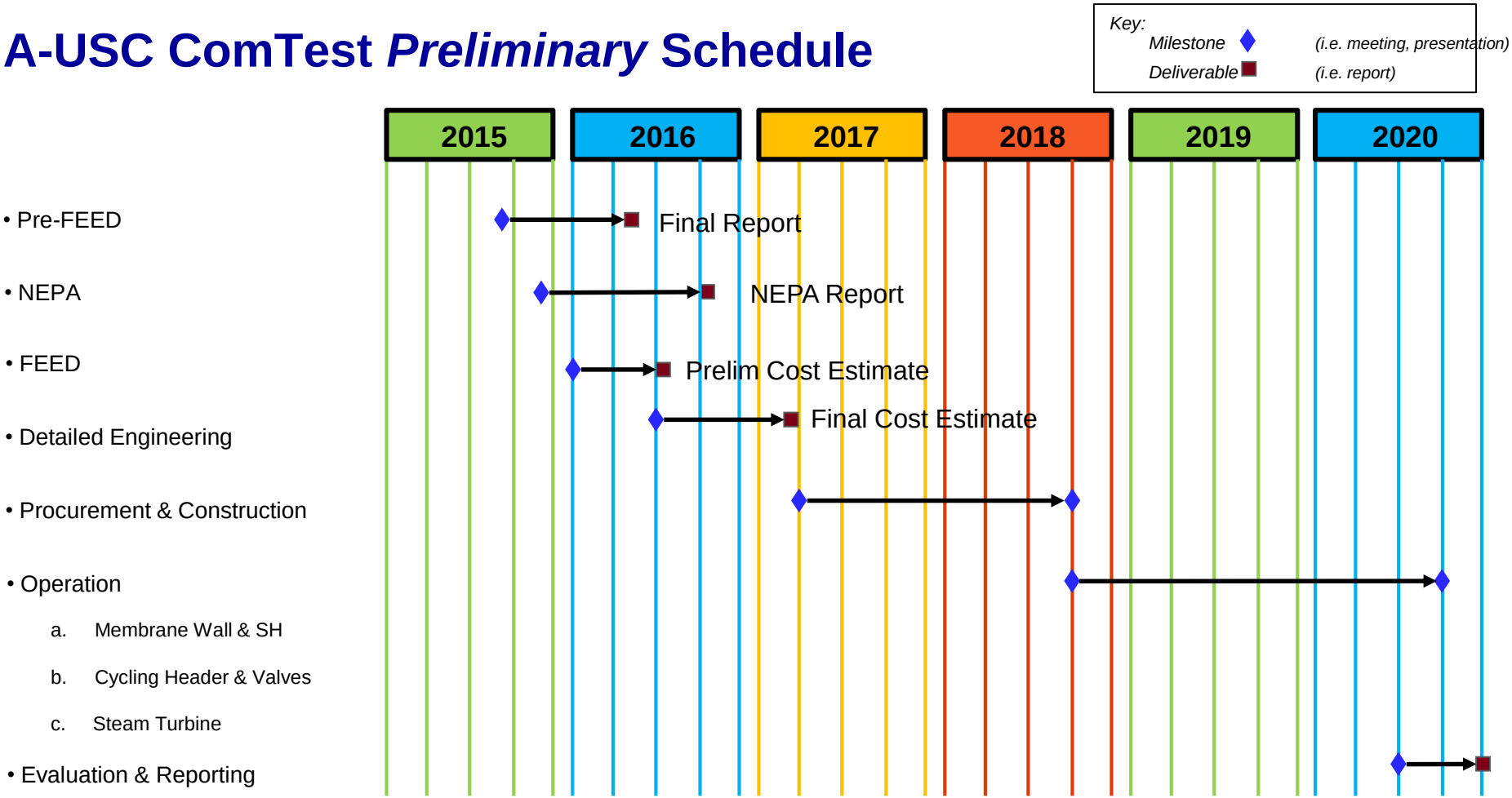
ComTest Schematic



Proposed A-USC Test Site Youngstown, Ohio (Former Ohio Edison Generation Plant)

Preliminary

A-USC ComTest *Preliminary* Schedule



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