T-Q Diagram and Heat Source Assessment – Preliminary Evaluation

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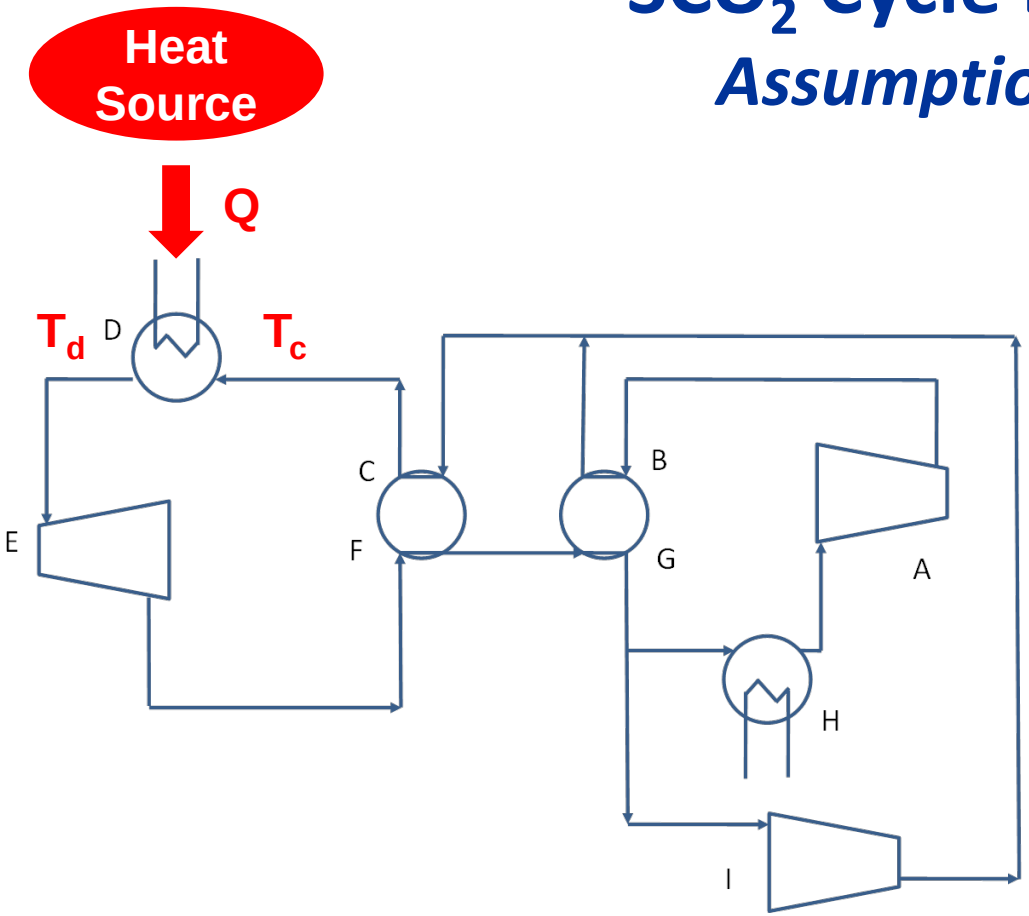
SCO_2 Heat Source Assessment

Objective

- **Preliminary assessment of the fossil fuel heat sources for integration with the supercritical CO_2 cycle**
  - PC, Air/Oxy
  - CFB, Air/Oxy
  - PFBC, Air/Oxy
- **Development of T-Q diagram to evaluate the effectiveness of various heat sources for supercritical CO_2 cycle**
  - Fossil fuels
  - Nuclear
  - Solar

SCO_2 Cycle Basis
Assumptions



Source: NETL

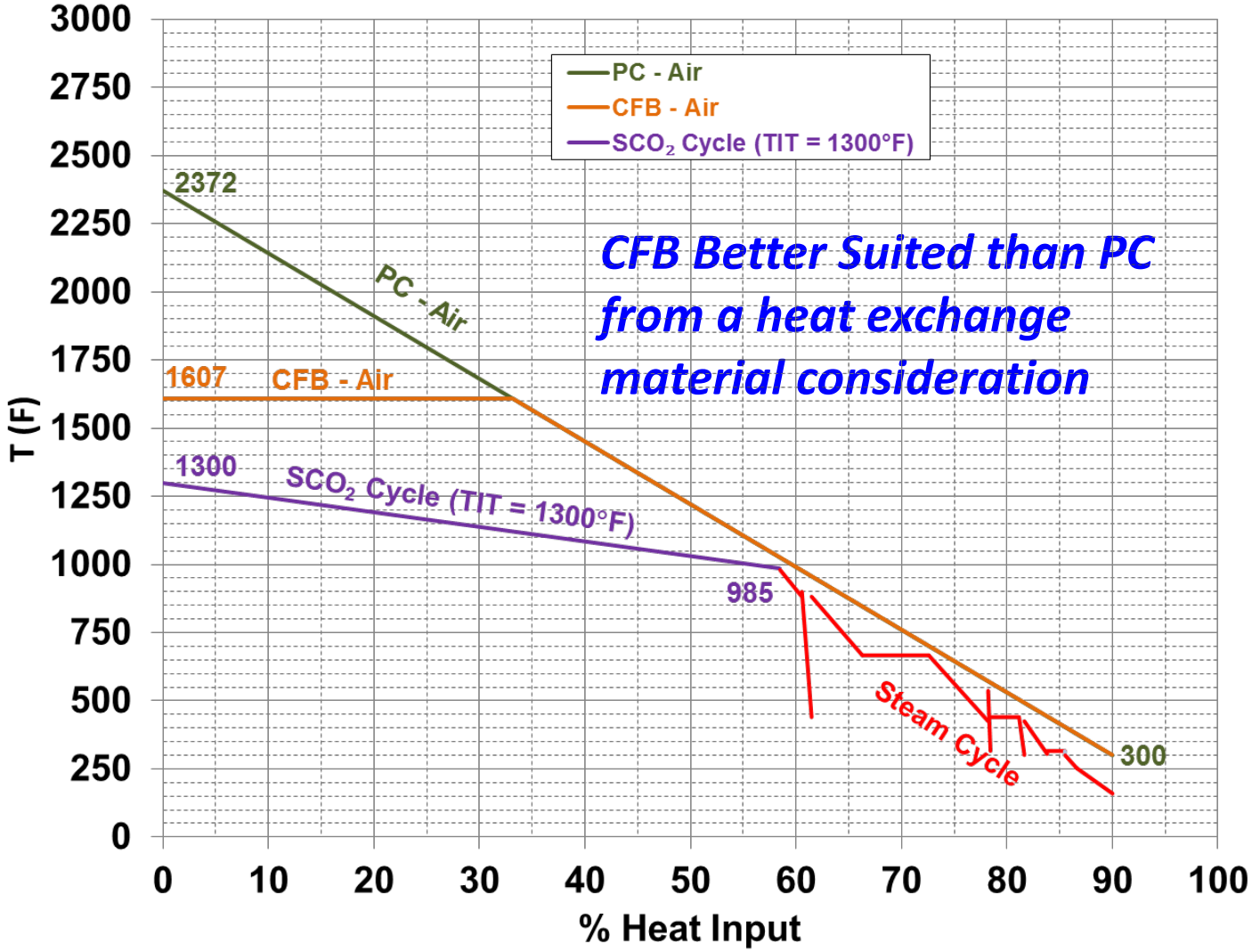
- **Recompression SCO_2 cycle**
  - Indirect
  - 2-stage
- **Preliminary cycle conditions:**
  - TIT = 1300 °F
  - $\eta_{turbine\ -\ isentropic} = 0.927$
  - $\eta_{compressor\ -\ isentropic} = 0.85$
  - $P_{turbine\text{-}exit} = 1150$ psia
  - $P_{turbine\text{-}inlet} = 3000$ psia
  - Pressure Ratio ~ 2.60
  - $T_C = 95$ °F
  - $T_c = 1100$ °F
  - $T_d = 1300$ °F

Preliminary cycle for discussion only – a more optimum cycle can be used to refine results

Source: NETL

Fossil Fuel Heat Sources and SCO_2 Cycle

T-Q Diagram – Air Based Combustion

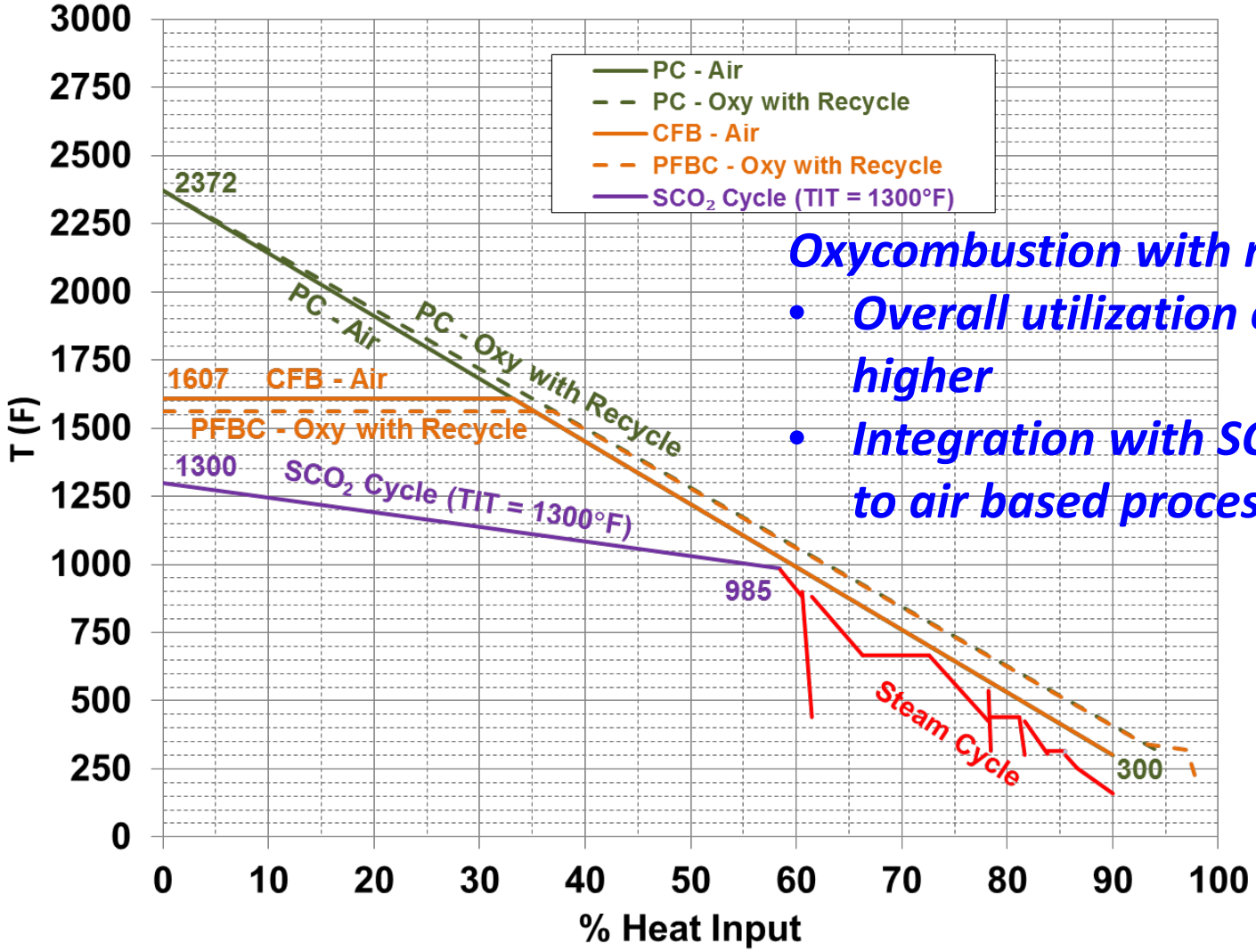


Source: NETL

Steam cycle from BB Case 13 – not optimized for current SCO_2 cycle

Fossil Fuel Heat Sources and SCO_2 Cycle

T-Q Diagram – Oxycombustion



Oxycombustion with recycle

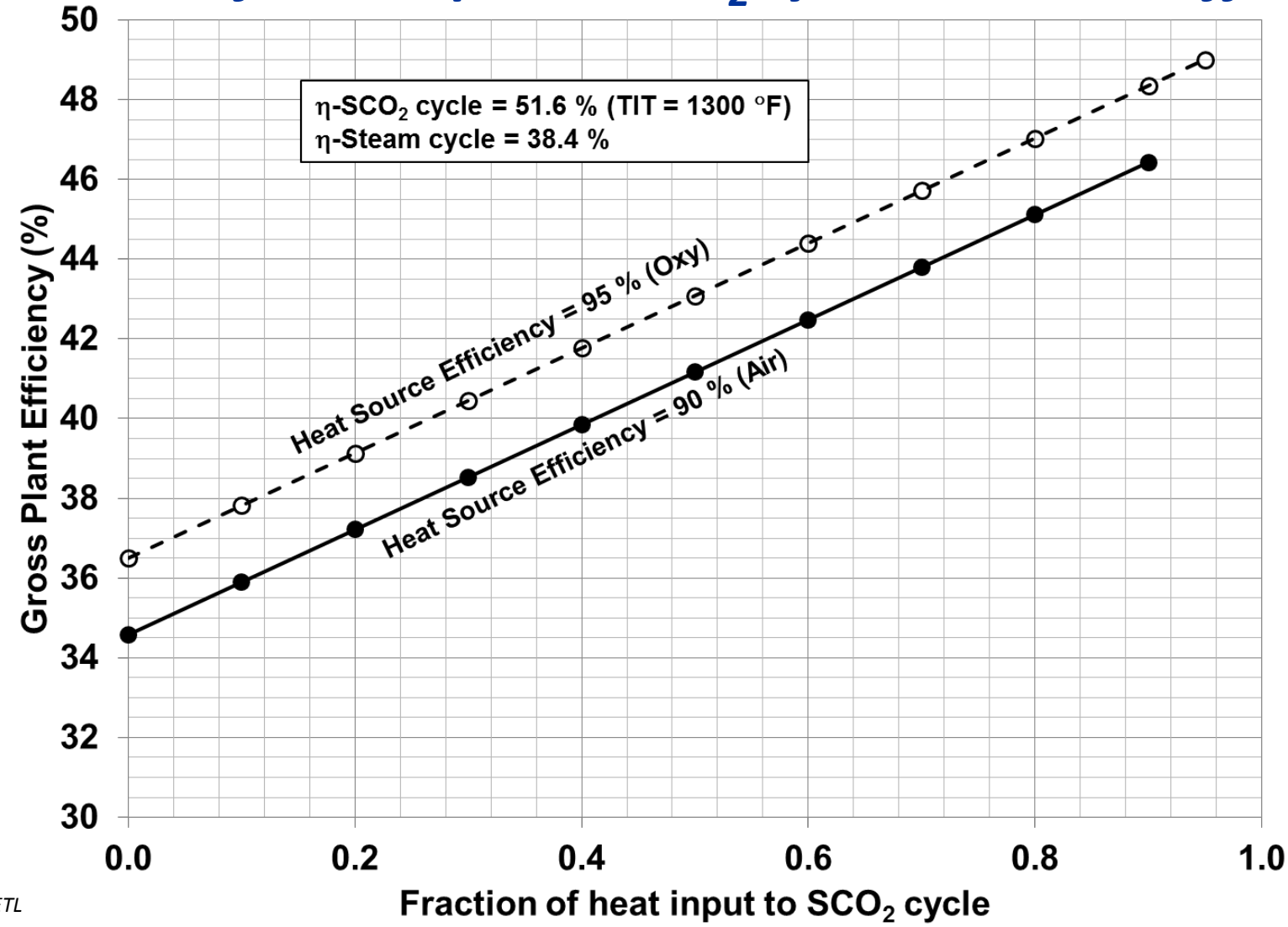
- ***Overall utilization of heat higher***
- ***Integration with SCO_2 similar to air based process***

Source: NETL

Steam cycle from BB Case 13 – not optimized for current SCO2 cycle

Fossil Fuel Heat Sources and SCO_2 Cycle

Fraction of heat input to SCO_2 cycle and Gross Efficiency

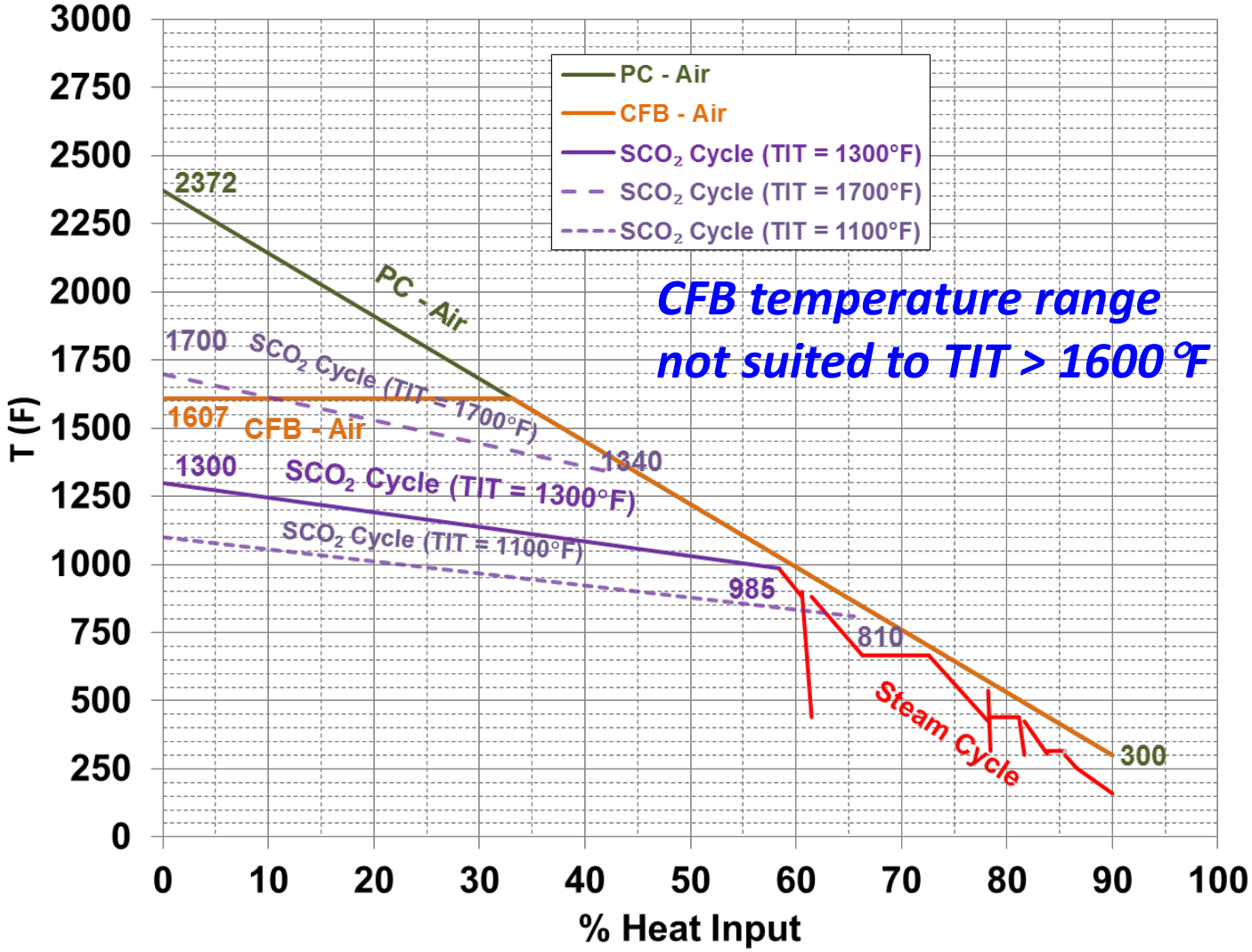


Source: NETL

Steam Cycle efficiency not adjusted based on heat input

Fossil Fuel Heat Sources and SCO_2 Cycle

T-Q Diagram – Effect of TIT

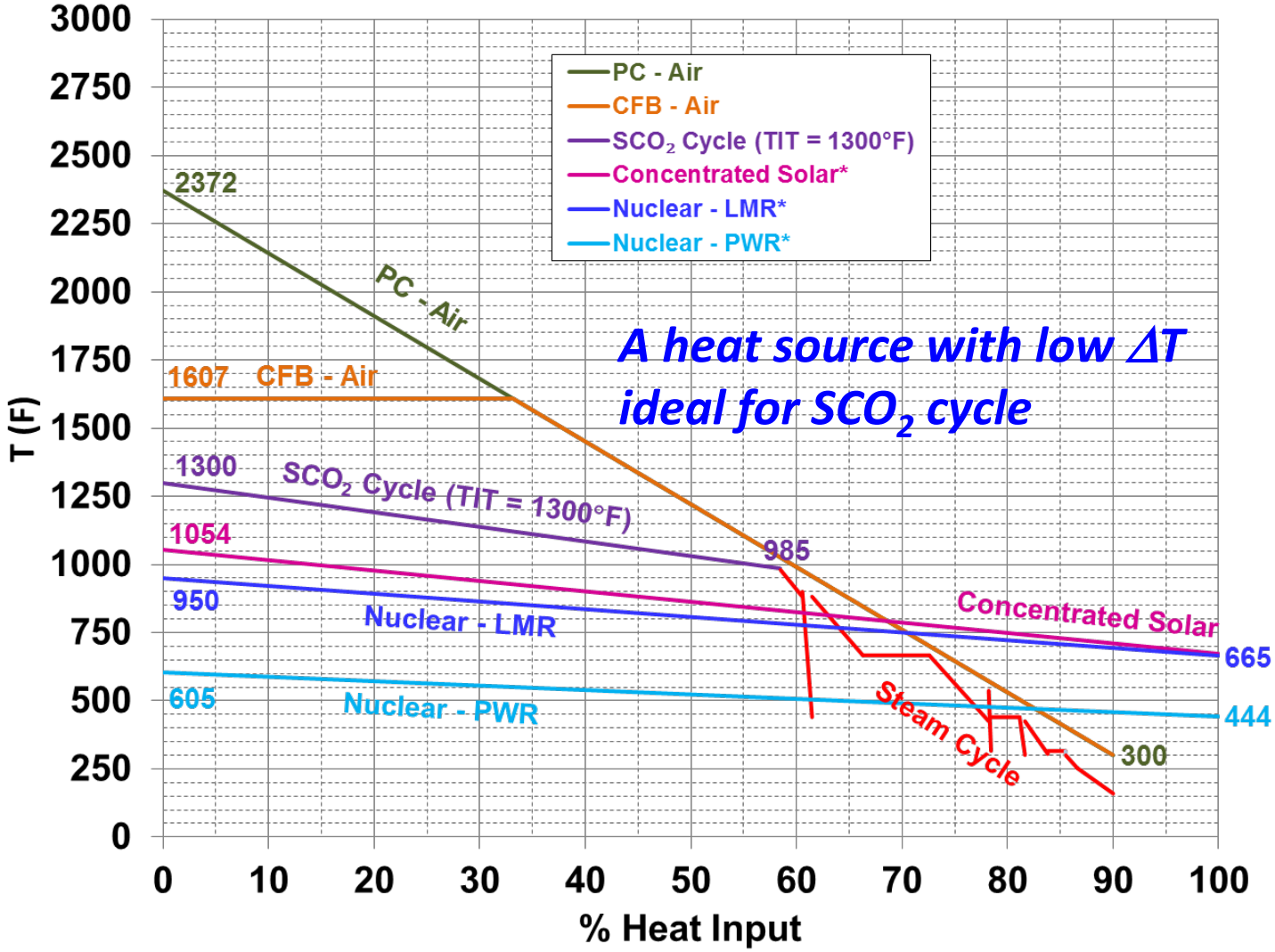


Source: NETL

Steam cycle will vary for different TIT

Heat Sources and SCO_2 Cycle

T-Q Diagram – Other Heat Sources

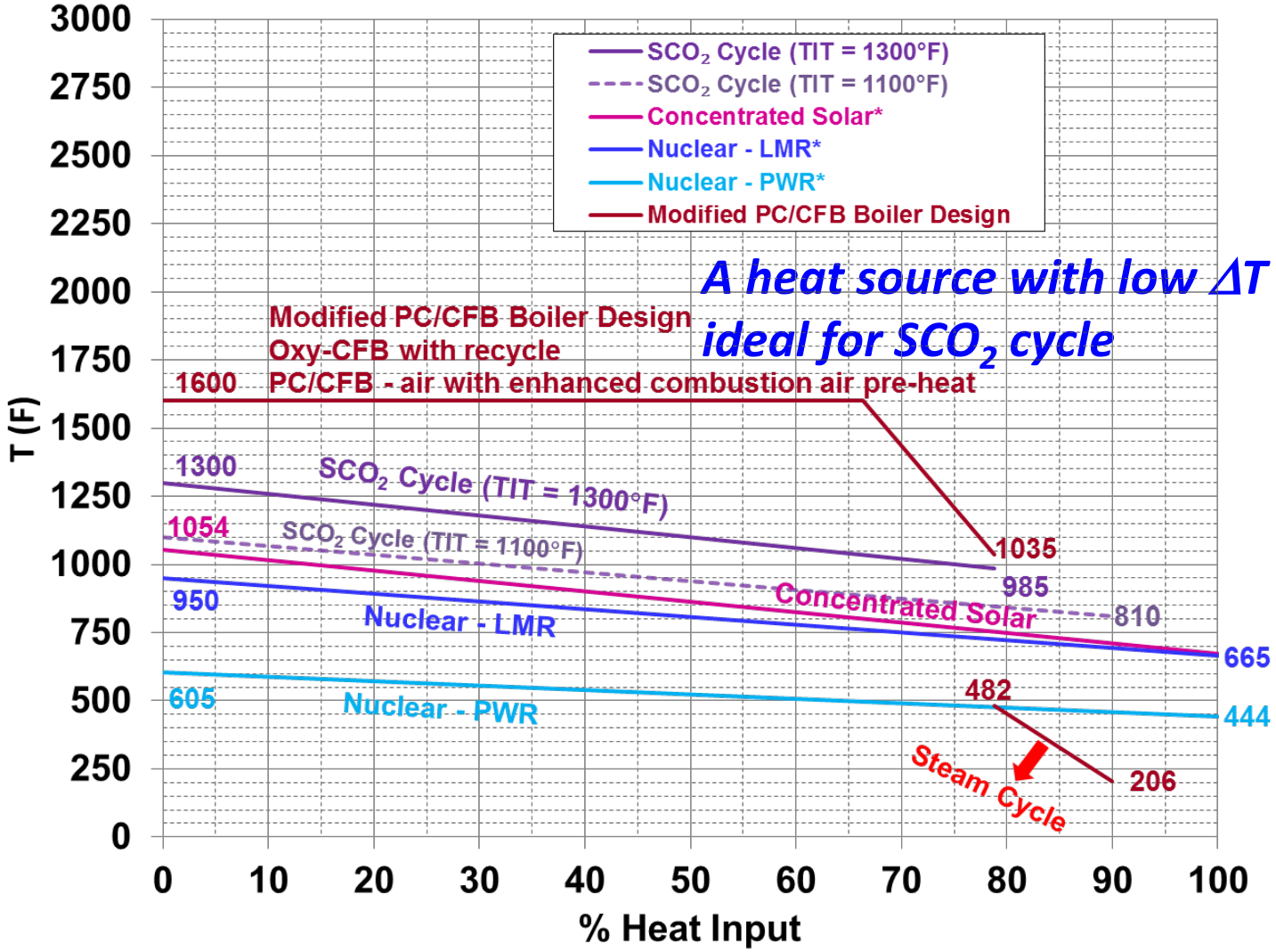


Source: NETL

Nuclear and Concentrated Solar better suited to SCO_2 cycle

Heat Sources and SCO_2 Cycle

T-Q Diagram – Modified PC/CFB Boiler Design

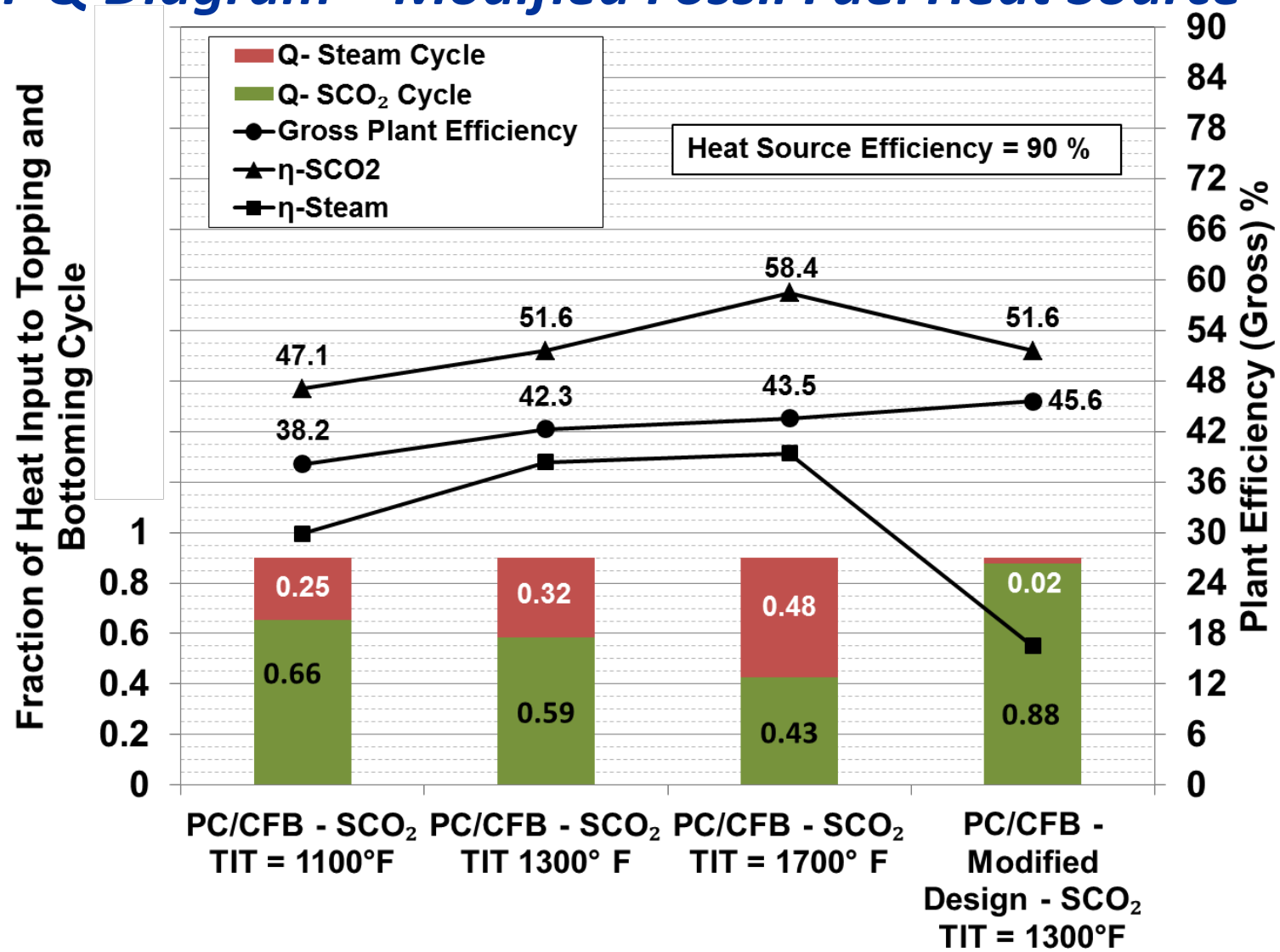


Source: NETL

Modified PC/CFB design suits the SCO_2 cycle well

Gross Plant Efficiency

T-Q Diagram – Modified Fossil Fuel Heat Source



Source: NETL

Preliminary for discussion – SCO_2 cycle not optimized

SCO_2 Heat Source Assessment
Oxy and Pressurized Configurations

- **Atmospheric Oxycombustion with recycle**
  - Heat utilization higher than air based process (less heat leaving via flue gas)
  - Integration with SCO_2 not significantly different from that with the air based process
- **PFBC Oxy with recycle**
  - Ability to capture part of the latent heat due to the higher flue gas dewpoint temperatures at higher pressure
  - Integration with SCO_2 similar to that of the atmospheric oxycombustion based process
  - Higher pressure helps in the thermal-hydraulic design of the heat exchange surfaces for the SCO_2 cycle

SCO_2 Heat Source Assessment

Conclusions

- **Current CFB (Air/Oxy) T-Q profile more suited to SCO_2 cycle (for TIT < CFB furnace temperature)**
  - PC, Air/Oxy – Furnace temperatures may be too high
  - Efficiency is not a differentiator here since fraction of heat input into SCo2 cycle is nearly the same in both CFB/PC
- **PC/CFB design needs to be modified to take advantage of the high efficiency SCO_2 cycle**
  - Maximize heat input into SCO_2 cycle
    - Heat exchanger design to impart heat to CO2 cycle at constant temperature by managing the combustion zone heat transfer
    - Recycling of flue gas in case of PC/CFB oxycombustion cases
    - Enhanced preheat of combustion air in PC/CFB air cases
- **SCO_2 cycle should be optimized to match the heat source better**
  - Higher number of stages
  - Use of low grade heat in cycle to offset recompression power

SCO_2 Heat Source Assessment

Design challenges

- **Design of the SCO_2 heat exchange surface**
  - Material limitations
- **PC/CFB furnace design**
  - Furnace thermal design
  - Furnace temperature control