BUILDING A WORLD OF DIFFERENCE

22 April 2016

DOE – CSP SUNSHOT
FLEXIBLC AND INTEGRATED FACILITY CONCEPTUAL DESIGN, COSTS AND SCHEDULE

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AGENDA (1 OF 3)

- Objectives and Deliverables
  - Project Funding
  - Project Integrated Test Facilities
  - Project Flexible Use Test Facilities

AGENDA (2 0F 3)

- Design Basis for Conceptual Design
  - General Arrangement for SCO2 Cycle
  - SCO2 Power Cycle Key Design Parameters (Preliminary)
  - Molten Salt Integrated Facility
  - Molten Salt 10 MW Integrated Facility Key Design Assumptions
  - Simplified MS Process Flow Diagram
  - Falling Particle Facility
  - Falling Particles Key Design Parameters (Preliminary)
  - Flexible Test Facility
  - Identify Critical Equipment to Test

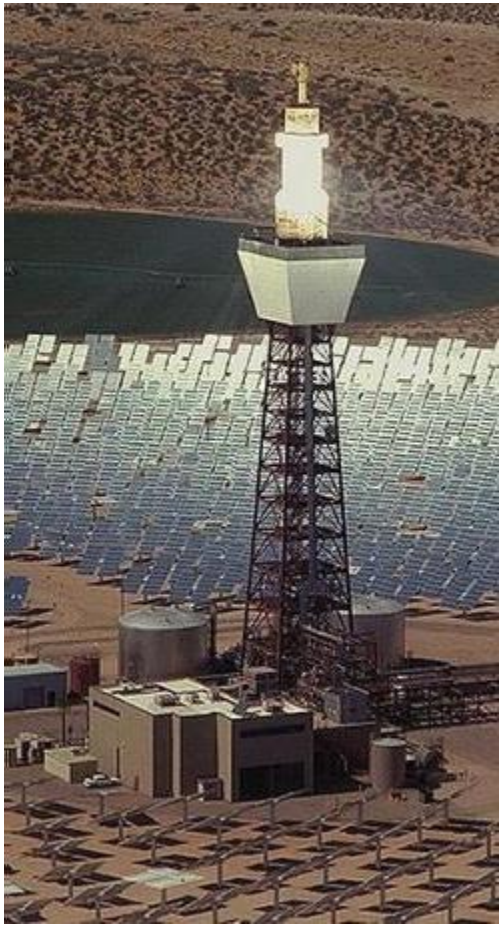
AGENDA (3 0F 3)

- Cost Estimates and Schedules
  - Capital Cost Estimates New Facilities
  - O&M Facilities
  - Schedule Lead Times from B&V Database and Suppliers
  - Contact Information

OBJECTIVES AND DELIVERABLES

PROJECT FUNDING

- **This project is funded by the Solar Energy Technologies Office, Concentrating Solar Power Program, under Contract DE-EE0006650**
  - Prime Contractor: Allegheny Science and Technology
  - Subcontractor: Black & Veatch Special Projects Corporation
  - Period of Performance: March 24, 2016 through June 30, 2016



PROJECT OBJECTIVES: INTEGRATED TEST FACILITIES

Develop System Definitions, including capital and O&M cost estimates and schedules, for 10 MWe Integrated Solar Power Tower Demonstration Facilities, with thermal storage, and a sCO2 power cycle, for:

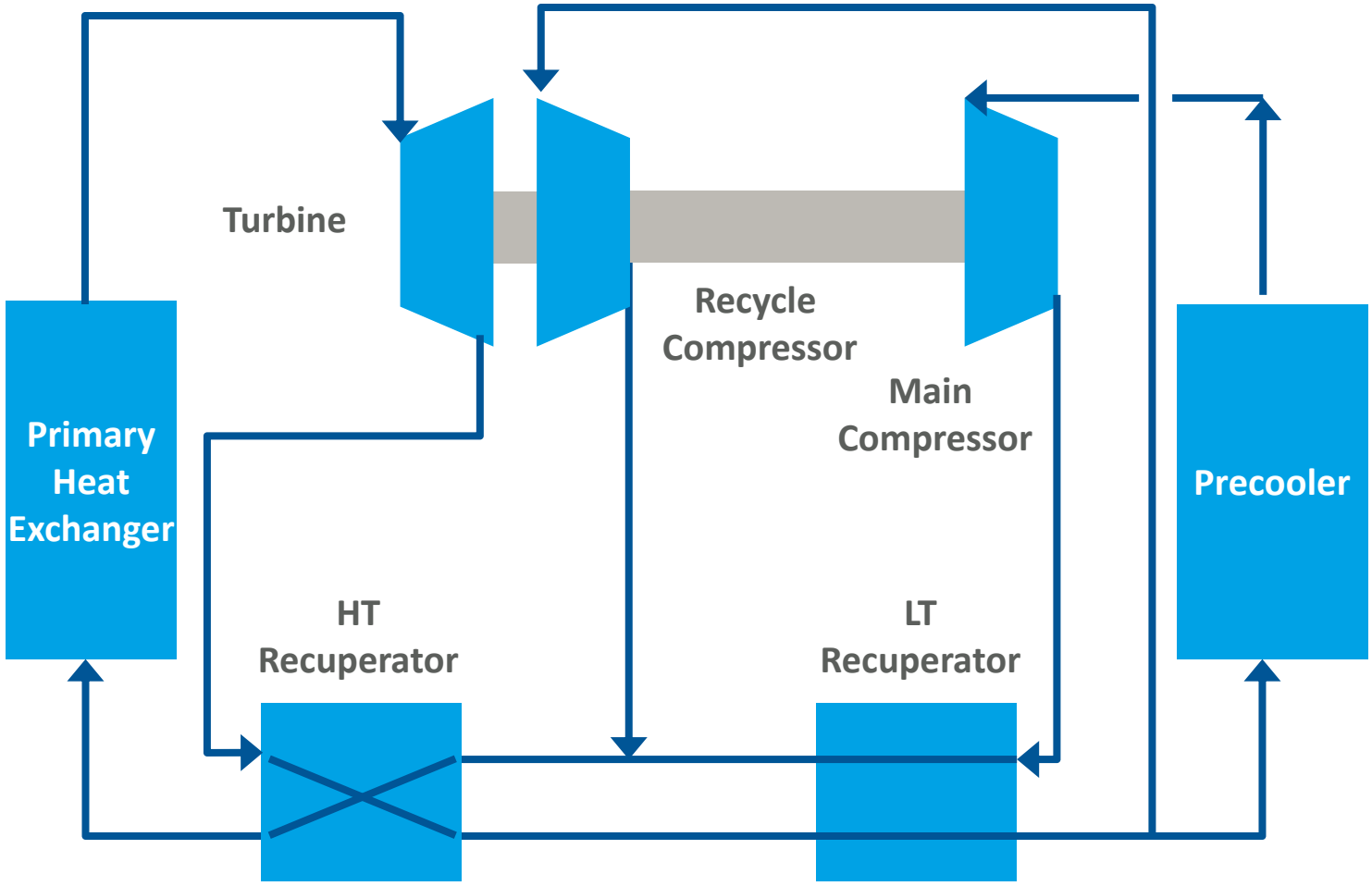
- Molten chloride salt heat transfer fluid
- Falling particle heat transfer fluid

PROJECT OBJECTIVES: FLEXIBLE USE TEST FACILITIES

- System definition, cost estimate, and schedule for a green field “flexible use” facility for component tests
- Assessment of the National Solar Thermal Test Facility (NSTTF) at Sandia Laboratories, Albuquerque, including cost for any necessary updates to support advanced SunShot technology component testing

DESIGN BASIS FOR CONCEPTUAL DESIGN

GENERAL ARRANGEMENT FOR sCO_2 CYCLE

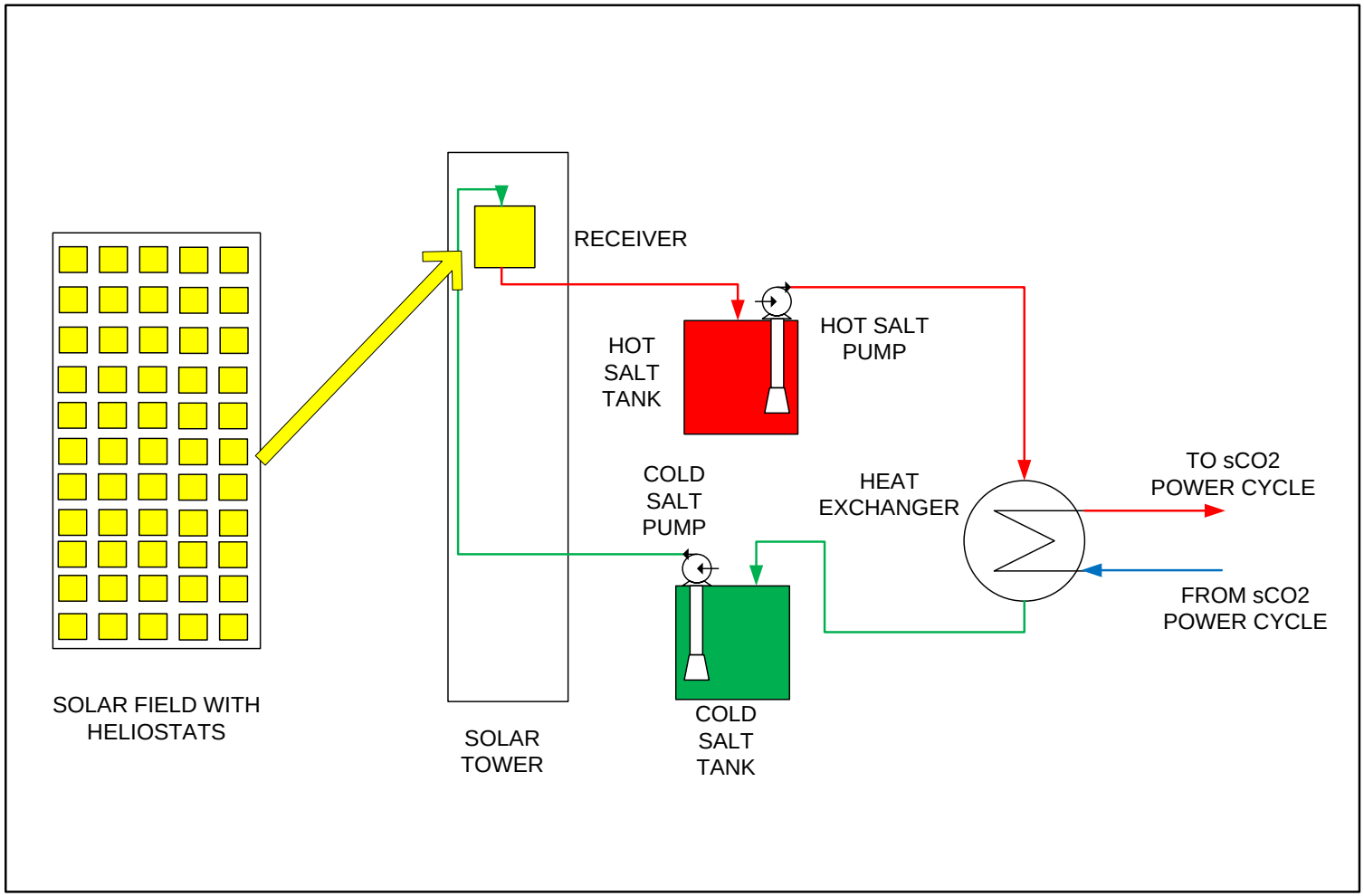


Recompression Closed Brayton Cycle

SCO2 POWER CYCLE
KEY DESIGN PARAMETERS (PRELIMINARY)

Plant Rating Basis		Target Design Basis
	Base Electrical Output (Net Plant)	~10,000 kW (Target)
	Base Efficiency (Net Plant)	≥50% (Target)
	Ambient Dry Bulb Temperature, C	Average Operating Day, Daggett CA
	Ambient Relative Humidity, %	Average Operating Day, Daggett CA
	Barometric Pressure, bara	0.9422 bara (610 m. elevation)
	Generator Power Factor	0.85
	Frequency	60 Hz
Plant Configuration		
	Configuration	Recompression Closed Brayton Cycle
	Condensing/Partial Condensing	No
	Reheat	No
	Recuperators	LT and HT
	Gas Cooler (Wet or Dry Cooling)	Dry
Turbine		
	Turbine Inlet Temperature, C	715
	Turbine Inlet Pressure, bara	250
Main Compressor		
	Pressure Ratio	~3.1
Recycle Compressor		
	Pressure Ratio	~3.1
	Recycle Flow Split, %	33%
HT Recuperator		
	Pinch, C	5
LT Recuperator		
	Pinch, C	5
Generator		
	Efficiency, %	97.4
	Windage and Mechanical Losses	0.75%
Gas Cooler/Pre-Cooler		
	Corresponding CO2 Outlet Temperature, C	35
Piping Pressure Drop Allowances, % of Inlet Pressure		
Piping Heat Loss Allowances, kJ/kg		
Electrical Losses and Major Loads/Systems in Service		

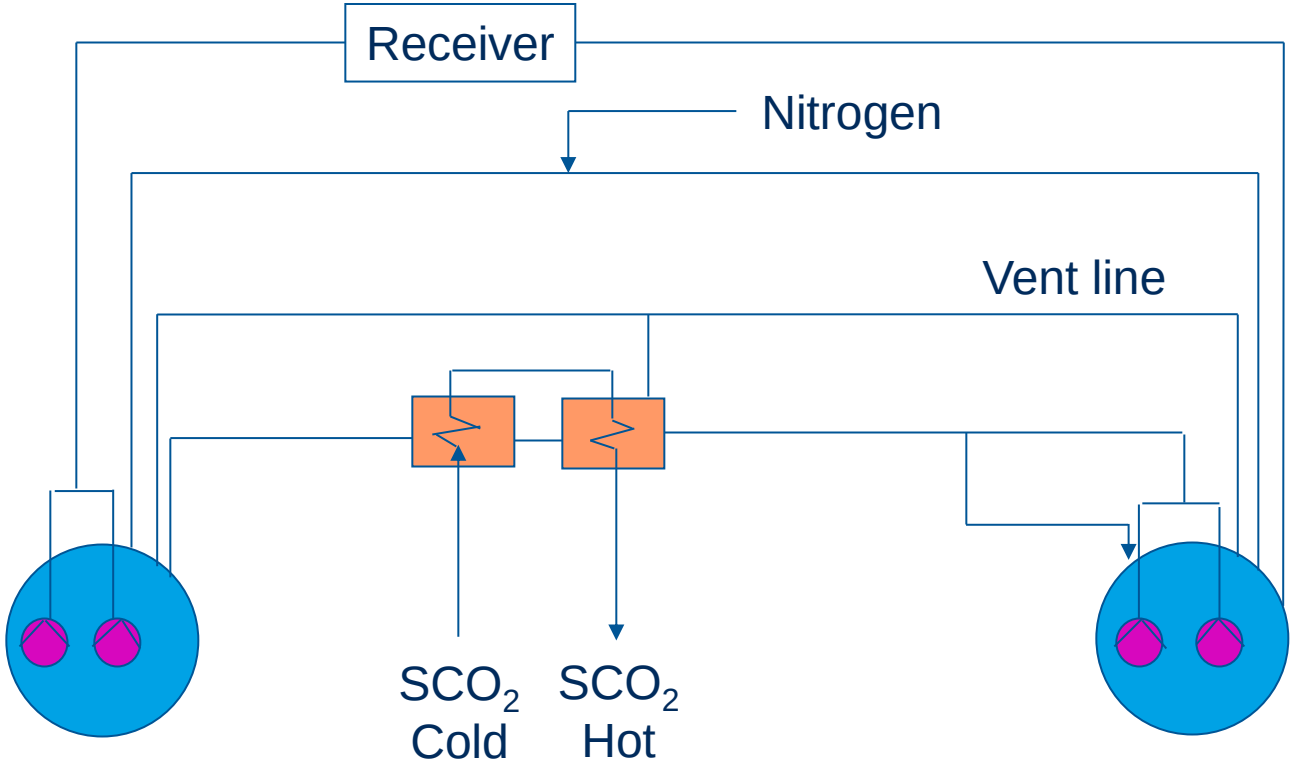
MOLTEN SALT INTEGRATED FACILITY



MOLTEN SALT 10 MW INTEGRATED FACILITY KEY DESIGN ASSUMPTIONS

Assumptions	Selected	Suggested Value
Molten Salt Type	MgCl2/KCl	MgCl/KCl
sCO2 Cycle		
MWe, Net	adjust later	10
MWe, Gross	12	12
sCO2, TiT, C		715
MS Hot Temp, C		750
sCO2 MC HX Temp, C		500
MWth, HX	24	
Solar Field		
Solar Multiple		1.3
Tower Height, m		50
Field Configuration		Surround
Heliostat, m2		Per SAM/NREL
MS System		
Hours of storage, h		4

SIMPLIFIED MS PROCESS FLOW DIAGRAM



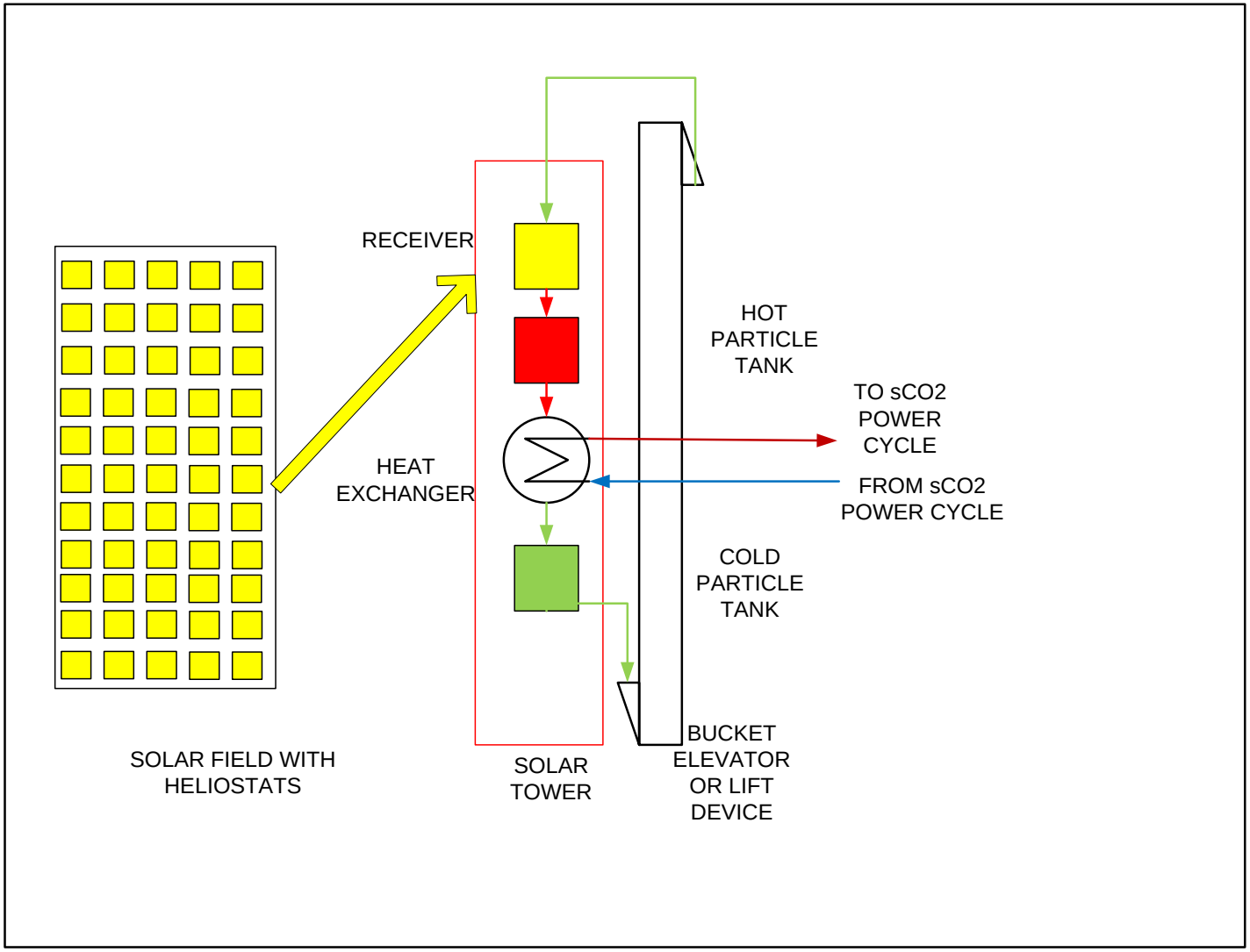
Cold Tank

1 Tank
12.9m D/7mH
240 m^3/h
Hd = 100m
Haynes 230

Hot Tank

1 Tank
13.4m D/7mH
32 mm t at base
200 m^3/h
Hd ≈ 40m
Haynes 230

FALLING PARTICLE INTEGRATED FACILITY



FALLING PARTICLE 10 MW INTEGRATED FACILITY KEY DESIGN PARAMETERS

Assumptions	Selected	Suggested Value
Falling Particles Type	CARBO Accucast ID50K	
sCO2 Cycle		
MWe, Net		10
MWe, Gross		12
sCO2, TiT, C		715
MWth, HX		24
Solar Field		
Solar Multiple		1.3
Tower height, m		50
Field Configuration		North facing
Receiver Configuration		Cavity
Heliostat reqts, m2		Per SAM/NREL
Receiver		
Hot Bin FP temperature, C	750	750
Cold Bin FP temperature, C	500	500
TES Bin (Hot) Design		
Hours of storage, h		4
MWh stored		96
Number of Bins, hot & cold	1 each	
TES Bin (Cold) Design		
FP flow rate, tonne/h		382
FP/sCO2 HX		
Arrangement	In tower, maybe fluidized bed	
FP/sCO2 HX Lift Device		
FP flow rate, tonne/h	xxx	382
Location	Outside tower	
Potential devices	Bucket elevators, skip hoist, etc.	

FLEXIBLE TEST FACILITY

- **OBJECTIVE REMINDER**
  - ENSURE EQUIPMENT IS TESTED TO SATISFY FUTURE LENDERS
  - TEST CRITICAL EQUIPMENT BEFORE BUILDING INTEGRATED FACILITY
  - CONTINUED MATERIAL/OTHER TESTS OUTSIDE OF FLEXIBLE FACILITY TO SUPPORT WORK

IDENTIFY CRITICAL EQUIPMENT TO TEST

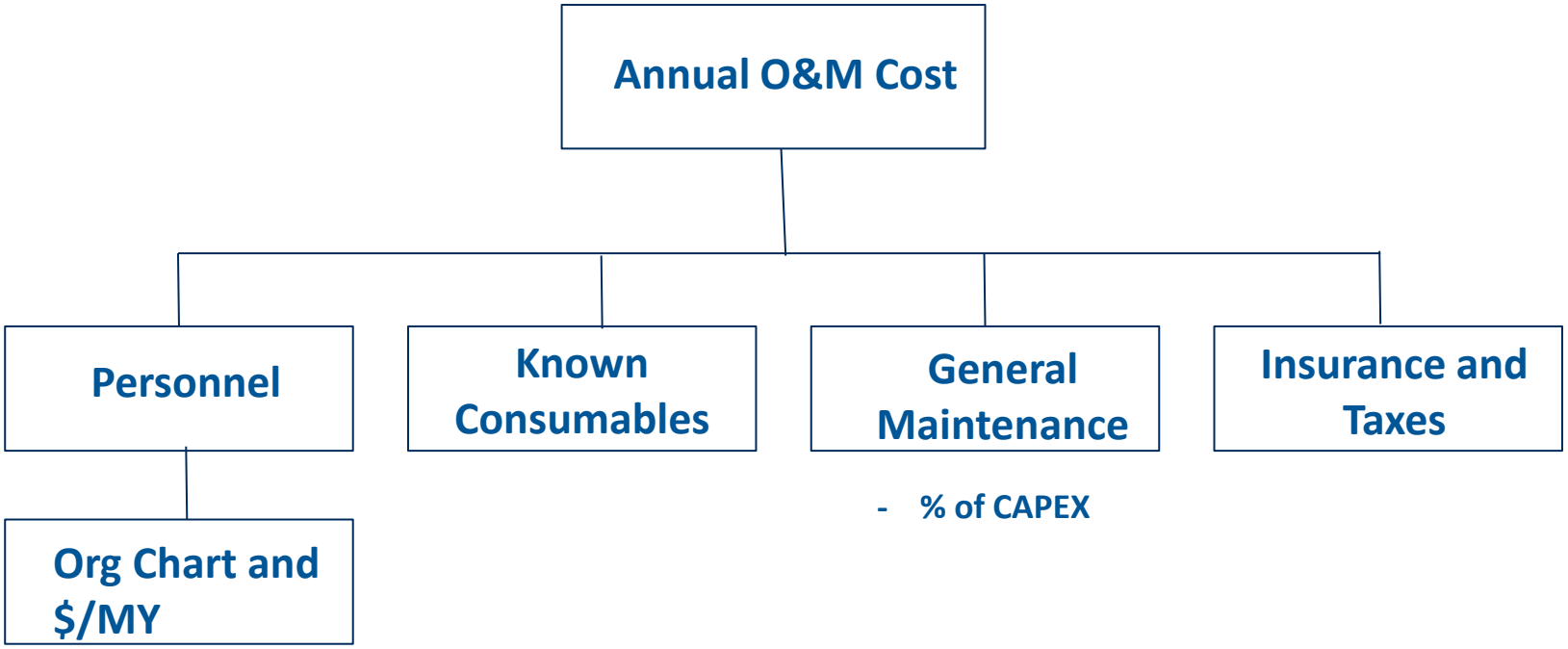
- **SIZE OF FACILITY (MWT)**
- **sCO2 COMPONENTS**
- **MOLTEN SALT SYSTEM**
  - PUMPS, PIPING & VALVES (HOT AND COLD)
  - HEAT EXCHANGERS (RECEIVER, MS TO CO2)
  - MS (IMPURITIES, ETC.)
  - MS TANK FOUNDATION DESIGN
- **FALLING PARTICLE SYSTEM**
  - HOT ELEVATORS, CHUTES, BINS, GATES
  - HEAT EXCHANGERS (CAVITY, FP/sCO2)
  - DUST COLLECTION

COST ESTIMATES AND SCHEDULES

CAPITAL COST ESTIMATES NEW FACILITIES

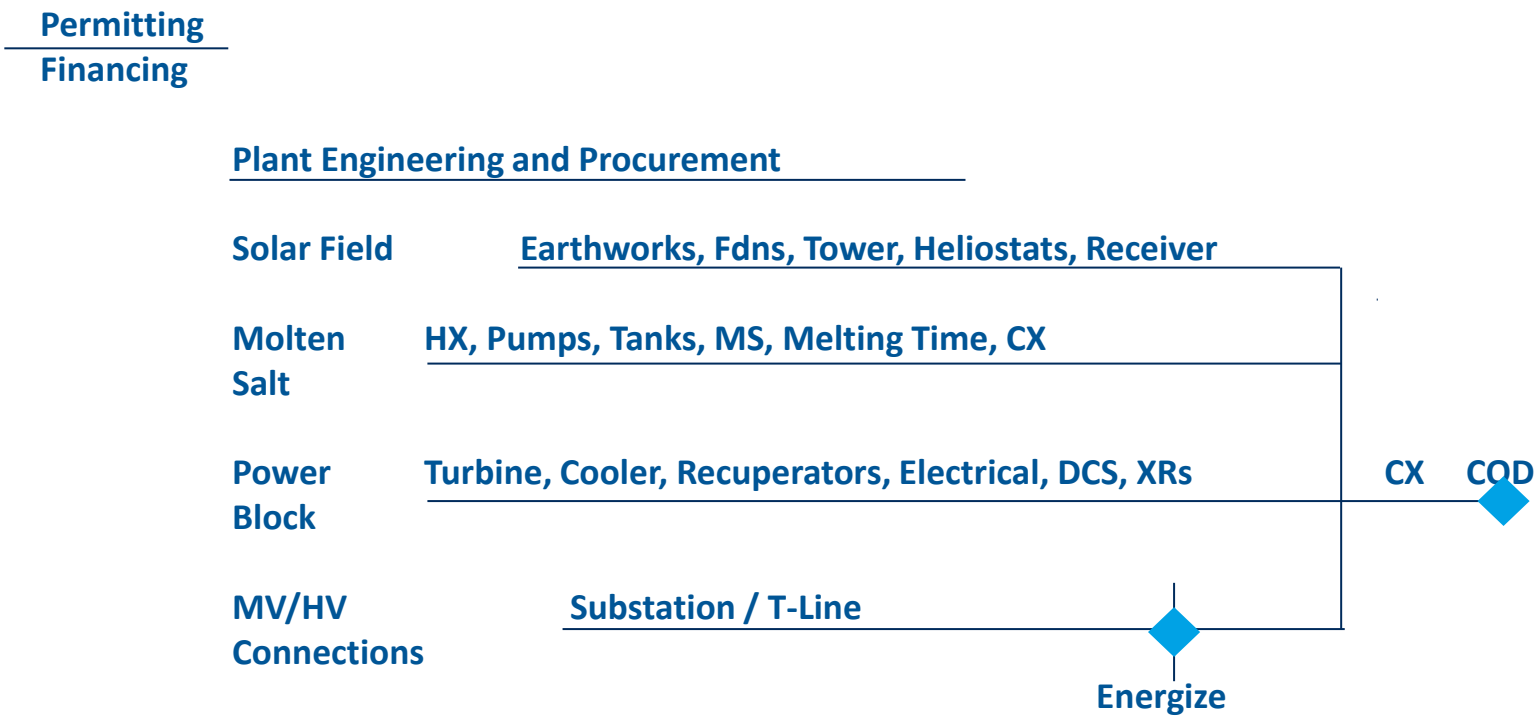
- **BOQ Based Estimate with Assumptions**
  - Conventional Equipment – B&V Database/Limited Quotes
  - sCO2 Equipment
    - TG and Recuperators: Obtain supplier ROM costs
  - New/Unproven Equipment: Molten Salt
    - Receiver: Obtain supplier ROM costs
    - MS/CO2 HX: As above or factor with assumptions
    - MS Pumps/Piping/Valves/etc: Factor with assumptions
    - Melting System: Factor with assumptions
  - New/Unproven Equipment: Falling Particle
    - Base costs on available research or factor with assumptions
- **Basis: Not EPC, Include Indirects**

O&M ESTIMATES



SCHEDULE

LEAD TIMES FROM B&V DATABASE AND SUPPLIERS



CONTACT INFORMATION

Geoff Galluzzo

GalluzzoG@bv.com

913-458-8671

Mike Eddington

EddintgonMJ@bv.com

913-458-2056

Larry Stoddard

StoddardL@bv.com

913-458-6551

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