Grid Connected Solar Power in India: Status and Prospects

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CEIC Seminar, CMU March 27th via video-conference

India and US (Selected Indicators for 2010)

Population	**1171 million**	**310.11 million**
GDP (PPP)	**3763 Billion 2005 US$ (3213 $/person)**	**13017 Billion 2005 US$ (41975 $/person)**
Primary Energy	**29.0 EJ**	**92.6 EJ**
Energy/person	**24.7 GJ/person/year**	**298.7 EJ**
Electricity/person	**644kWh/capita/year**	**13361 kWh/capita/year**
CO2 emissions	**1626 Million tonnes**	**5369 Million tonnes**
Per person	**1.39 tonnes /capita/year**	**17.31 tonnes /capita/year**
Per GDP	**0.43 kg /US$ ppp**	**0.41 kg /US$ ppp**

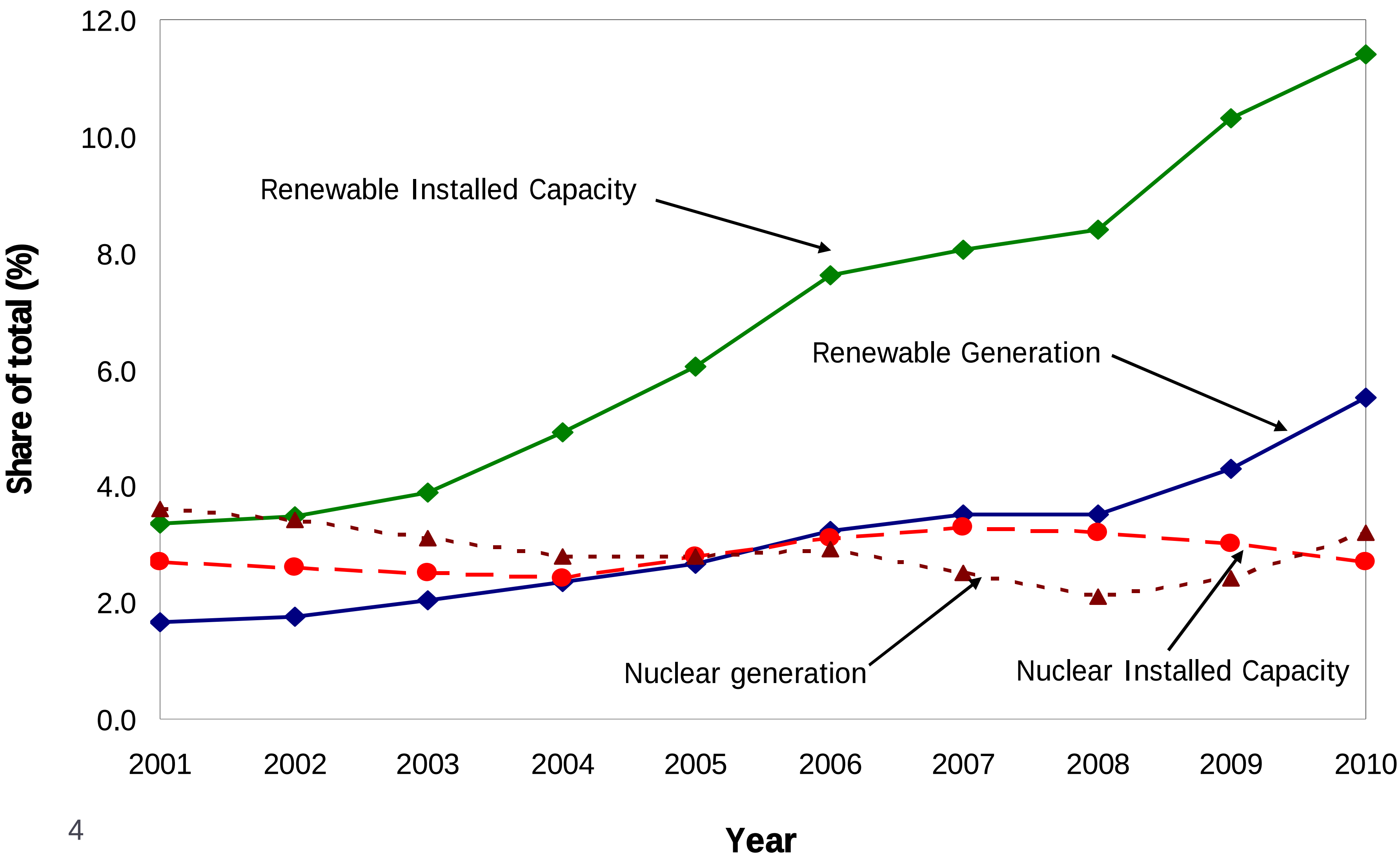
Source: IEA, Key World Energy Statistics 2012

Renewable installed capacity and generation

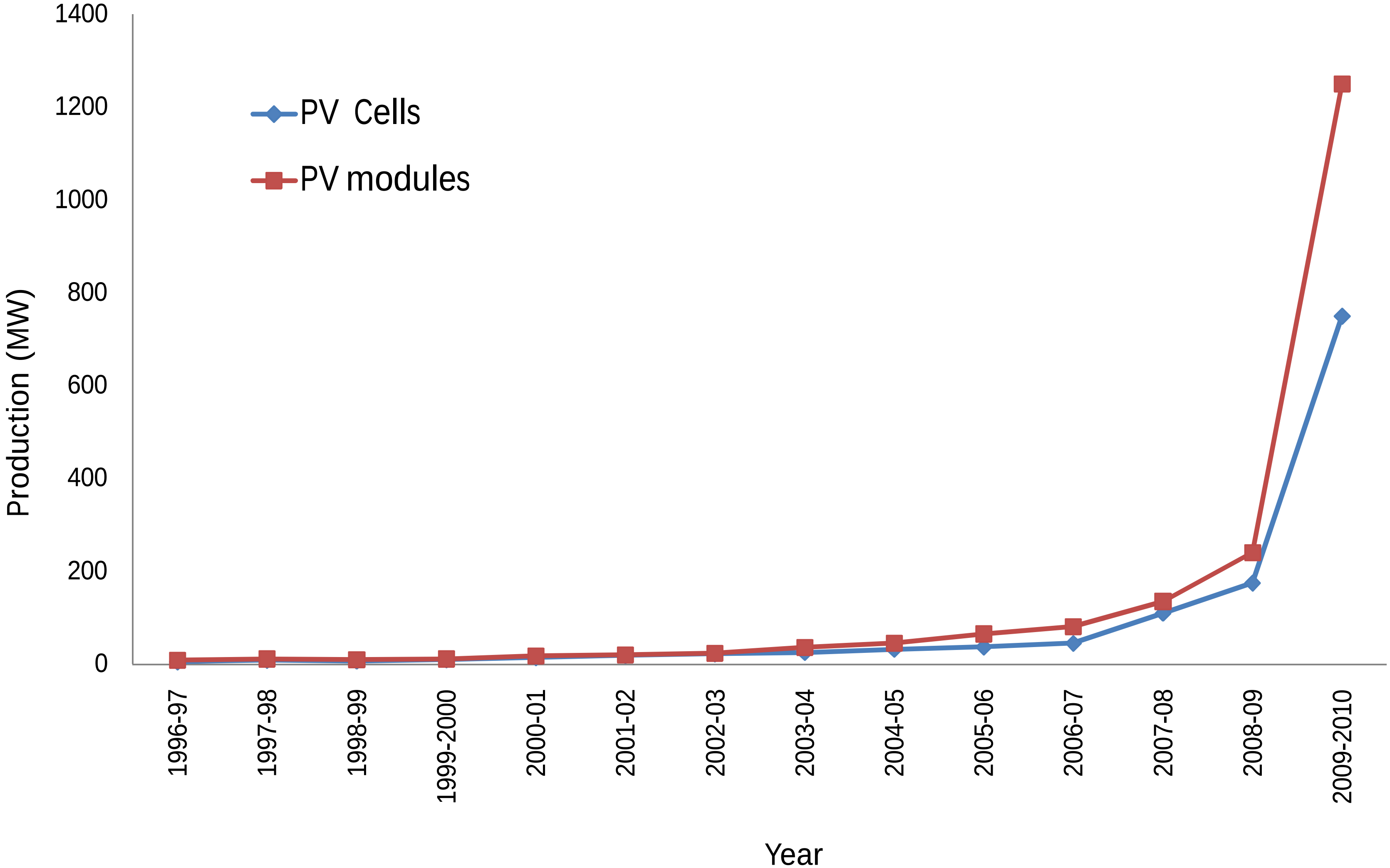
	Installed Capacity* (MW)	Estimated Capacity factor	Estimated Generation (GWh)
Wind	18635	14%	22854
Biomass Power	1264	70%	7751
Bagasse Cogeneration	2301	60%	12094
Small Hydro	3552	40%	12446
Waste to Energy	96	50%	420
Solar PV	1447	20%	2535
Total	27295	25%	58101

*as on 28.02.2013 MNRE website: www.mnre.gov.in

Renewable Share in Power



Annual PV module / cell Production



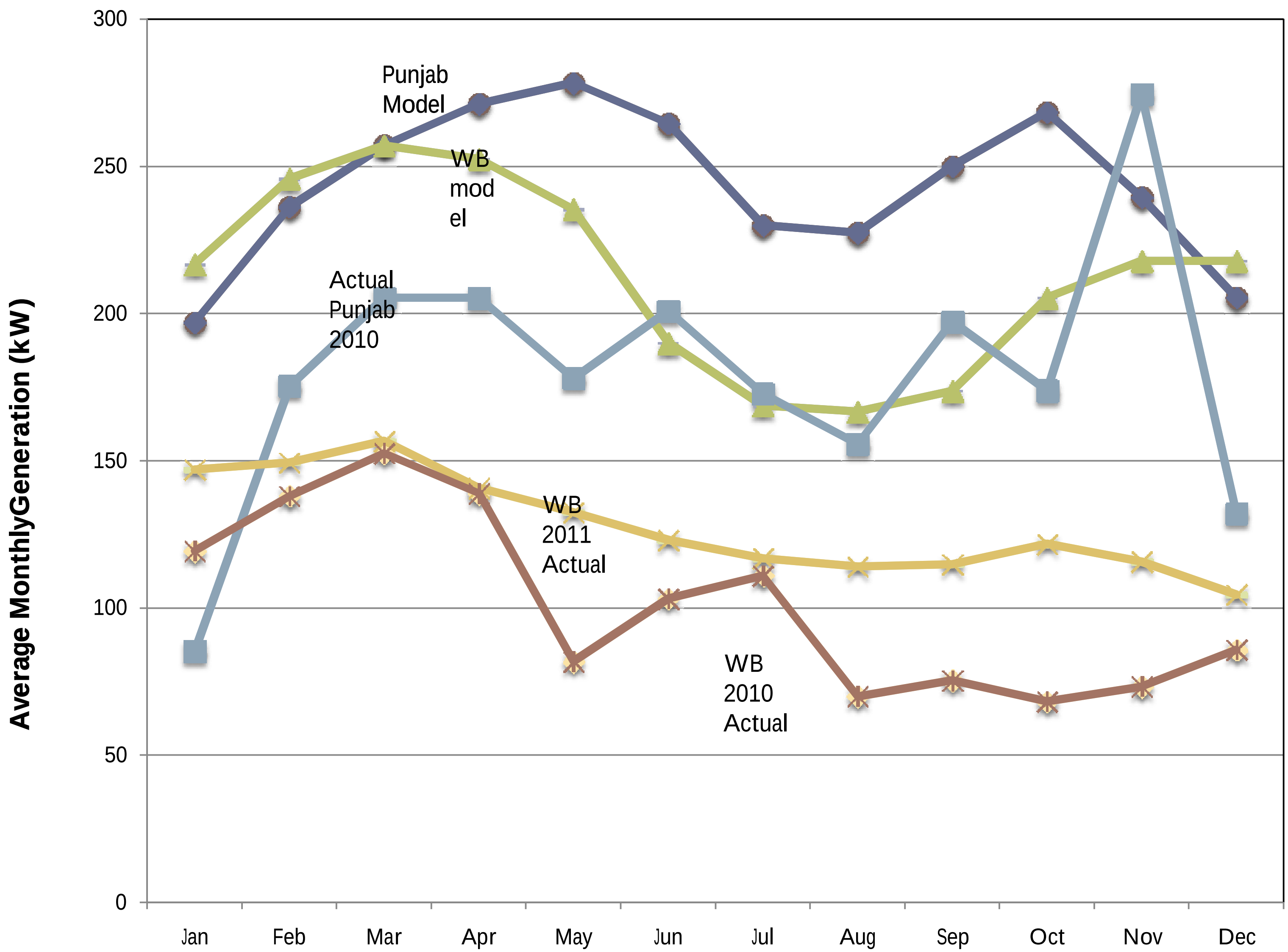
Solar Mission- JNSM Targets

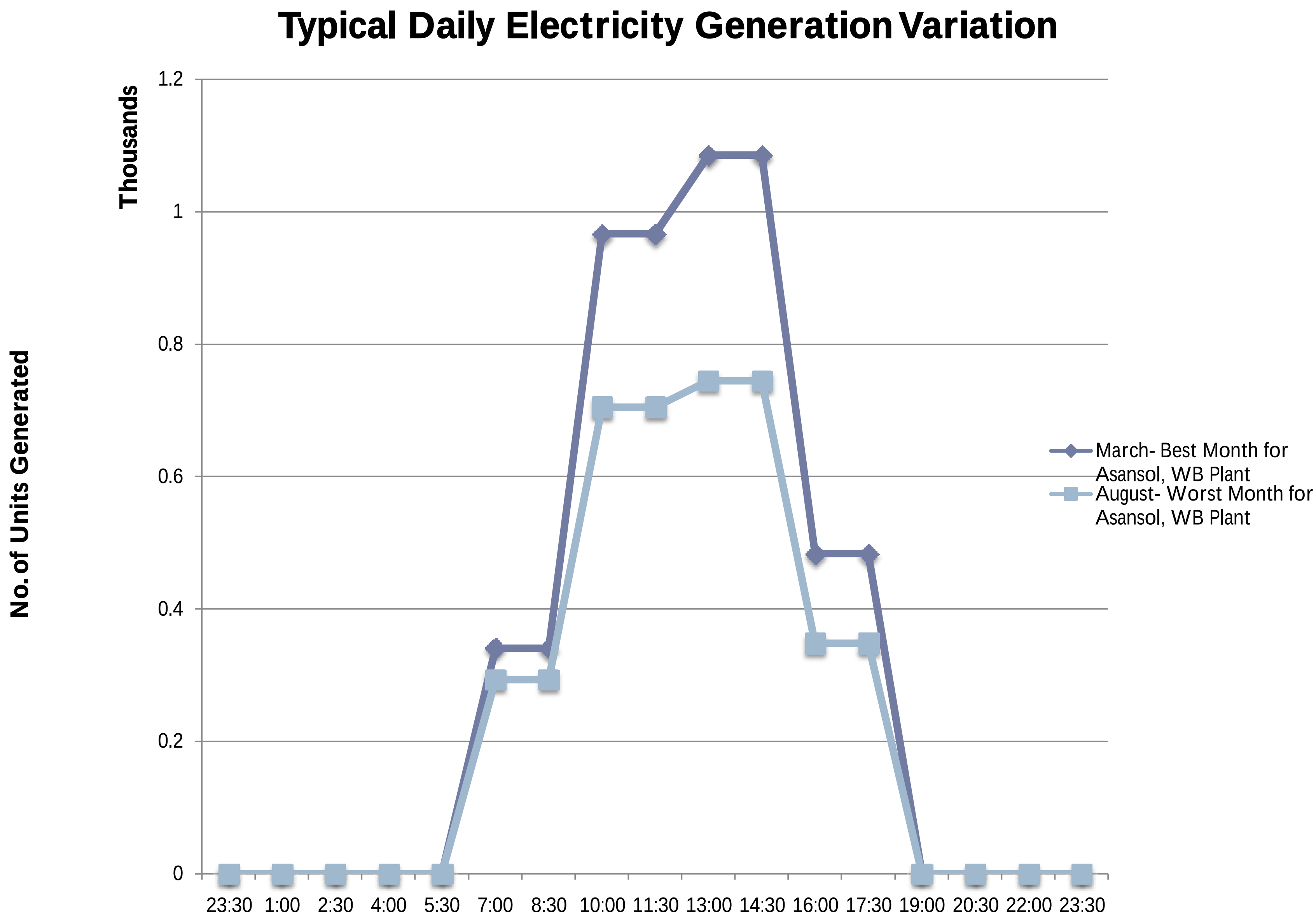
S.No.	Application segment	Target for Phase I (2010-13)	Target for Phase II (2013-17)	Target for Phase III (2017-22)
1.	Solar collectors	7 million sq meters	15 million sq meters	20 million sq meters
2.	Off grid solar applications	200 MW	1000 MW	2000 MW
3.	Utility grid power, including roof top	1000-2000 MW	4000-10000 MW	20000 MW

Megawatt size grid solar power plants – India

Project Developer	Project site	Capacity (MW)	PV Technology	Operation in Days	Generation in MWh
WBGEDCL*	Jamuria, Asansol, West Bengal	1	Crystalline Silicon Sept.09 - Aug. 10	614 (365)	1879.9 12.29%
Azure Power	Awan, Amritsar, Punjab	1	Crystalline Silicon Dec.09 to Nov.10	577 (365)	3312 16.92%
Mahagenco	Chandrapur, Maharashtra	1	a-Si Thin Films May 10 to Apr.11	448 (365)	1654.2 15.39%
Reliance Industries	Nagaur, Rajasthan	5	Crystalline Silicon, Thin Films, CPV	352 July 10 to June 11	7473.3 18.8%
Saphhire Industrial	Sivaganga, Tamil Nadu	5	a-Si Thin Films	190	4271.3
Sri Power	Chittoor, Andhra Pradesh	2	Crystalline Silicon CdTe Thin Film	92	901.9

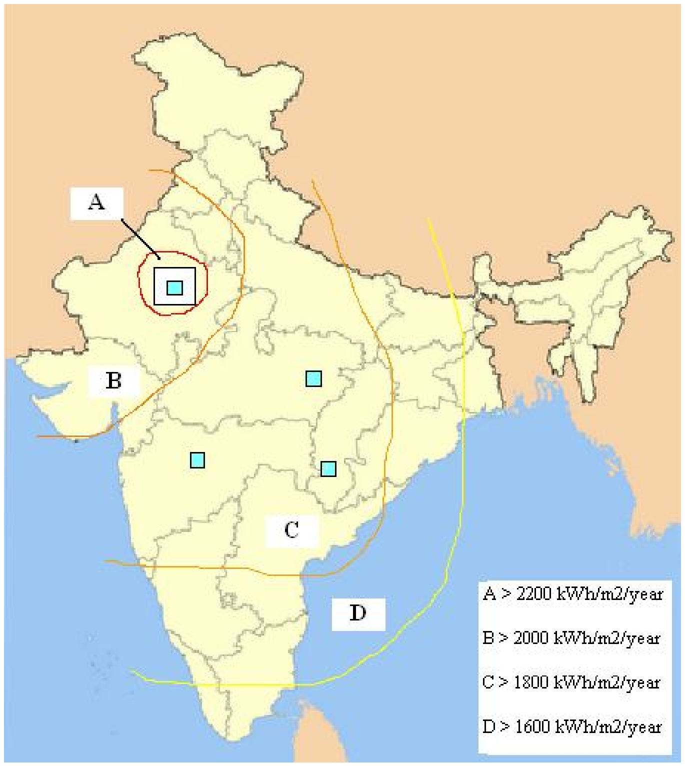
Source: 32/54/2011-12/PVSE, MNRE


Average MonthlyGeneration (kW)
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Punjab Model
WB mod el
Actual Punjab 2010
WB 2011 Actual
WB 2010 Actual



Typical Daily Electricity Generation Variation
Thousands
No. of Units Generated
1.2
1
0.8
0.6
0.4
0.2
0
23:30
1:00
2:30
4:00
5:30
7:00
8:30
10:00
11:30
13:00
14:30
16:00
17:30
19:00
20:30
22:00
23:30
March- Best Month for Asansol, WB Plant
August- Worst Month for Asansol, WB Plant

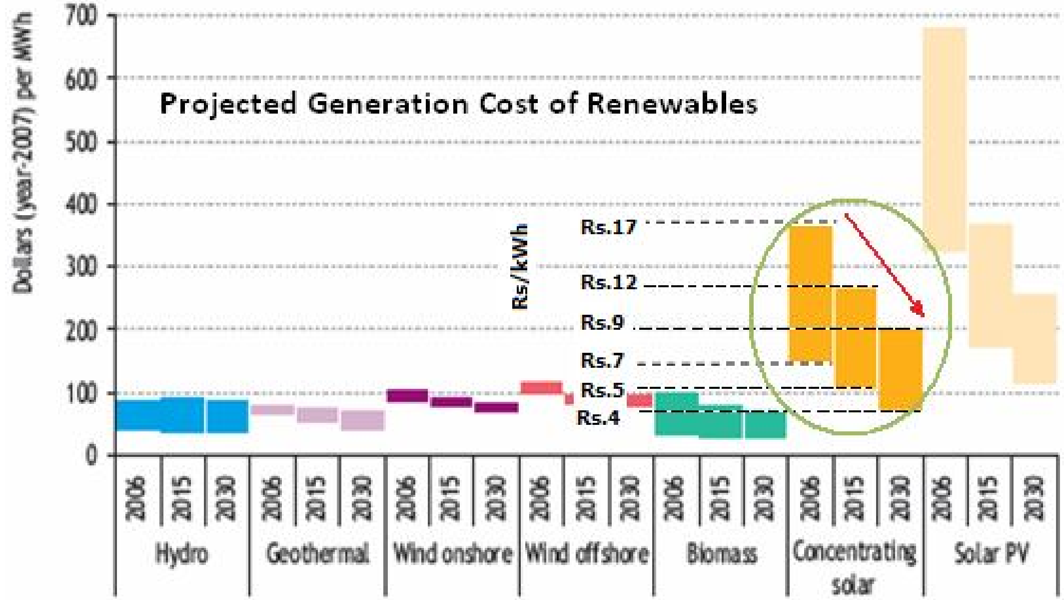
Challenges



Solar Insolation and area required

□ = 2500 sq.km

■ = 625 sq.km

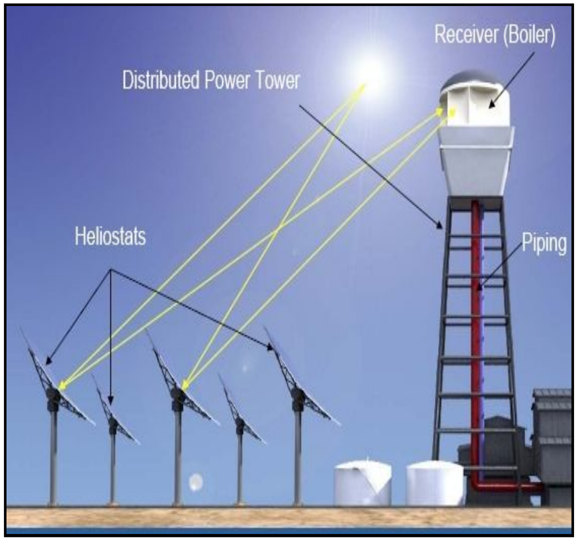


Source: World Energy Outlook – 2008, International Energy Agency

1. Limited experience in CSP in the country
2. Need for cost reduction
3. Need for indigenous technology, system development
4. Need for demonstration, public domain information

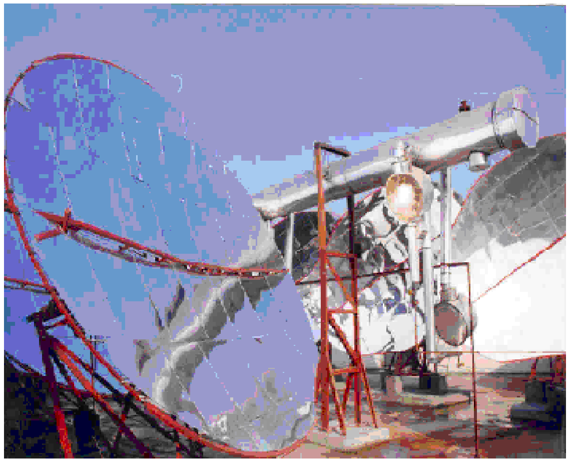
Solar Concentrators

Parabolic Trough



Heliostat

CLFR Technology



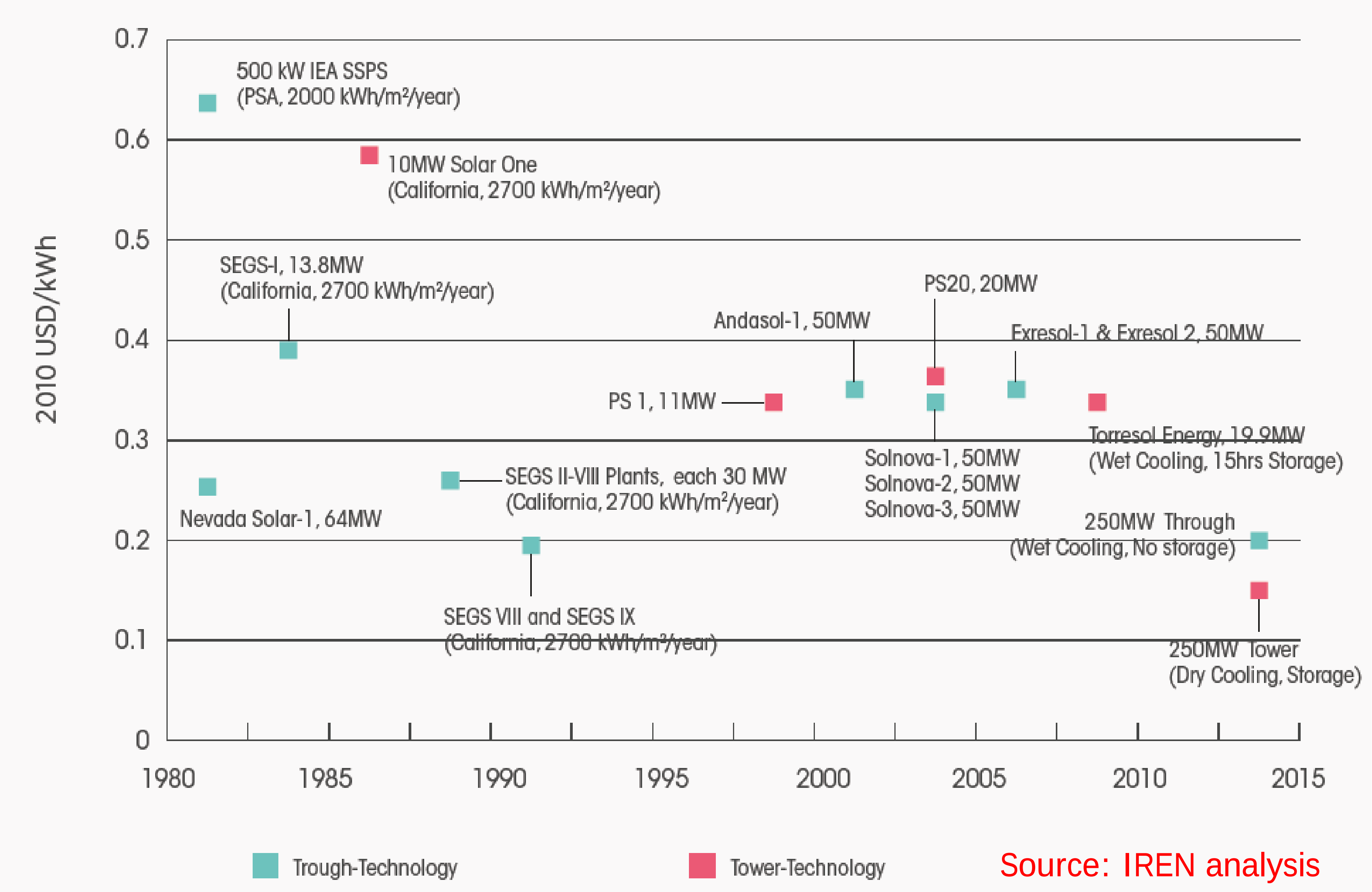
Scheffler paraboloid dish

Arun Technology

Solar Thermal Technologies

	Companies	**Operating temp.**	**Efficiency, η**	**Remarks**
Parabolic Trough	Abener, Thermax, KIE Solatherm	350-400°C	Peak 14-20% 11-16% Annual	Commercial
Linear Fresnel Reflector	KG Design, Areva	220-250°C	Peak 18% Annual 13%	Lower cost
Dish	Gadhia Solar, Clique, WRST, Birla Terra Joule, ATE	200 - 700°C	Peak 30% Annual 12-25%	Solar heating cooking
Heliostats Solar Tower	E-Solar (ACME) 2.5 MW at Bikaner Sunborne	450-565°C	23-25% 7-20%	

Estimated LCOE for existing and proposed Parabolic Trough and Solar Tower CSP Plants



Source: IREN analysis

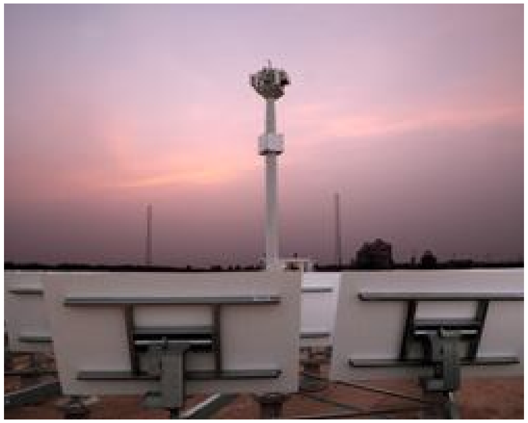
Solar Tower

E-Solar – Acme partnership

First grid connected plant in India 2011

2.5 MW out of 10 MW installed Bikaner Rajasthan

Double-axis software-mirror tracking system
Lightweight, small size
1 m^2 flat mirrors



Plant output not stabilised – insolation, auxiliary consumption

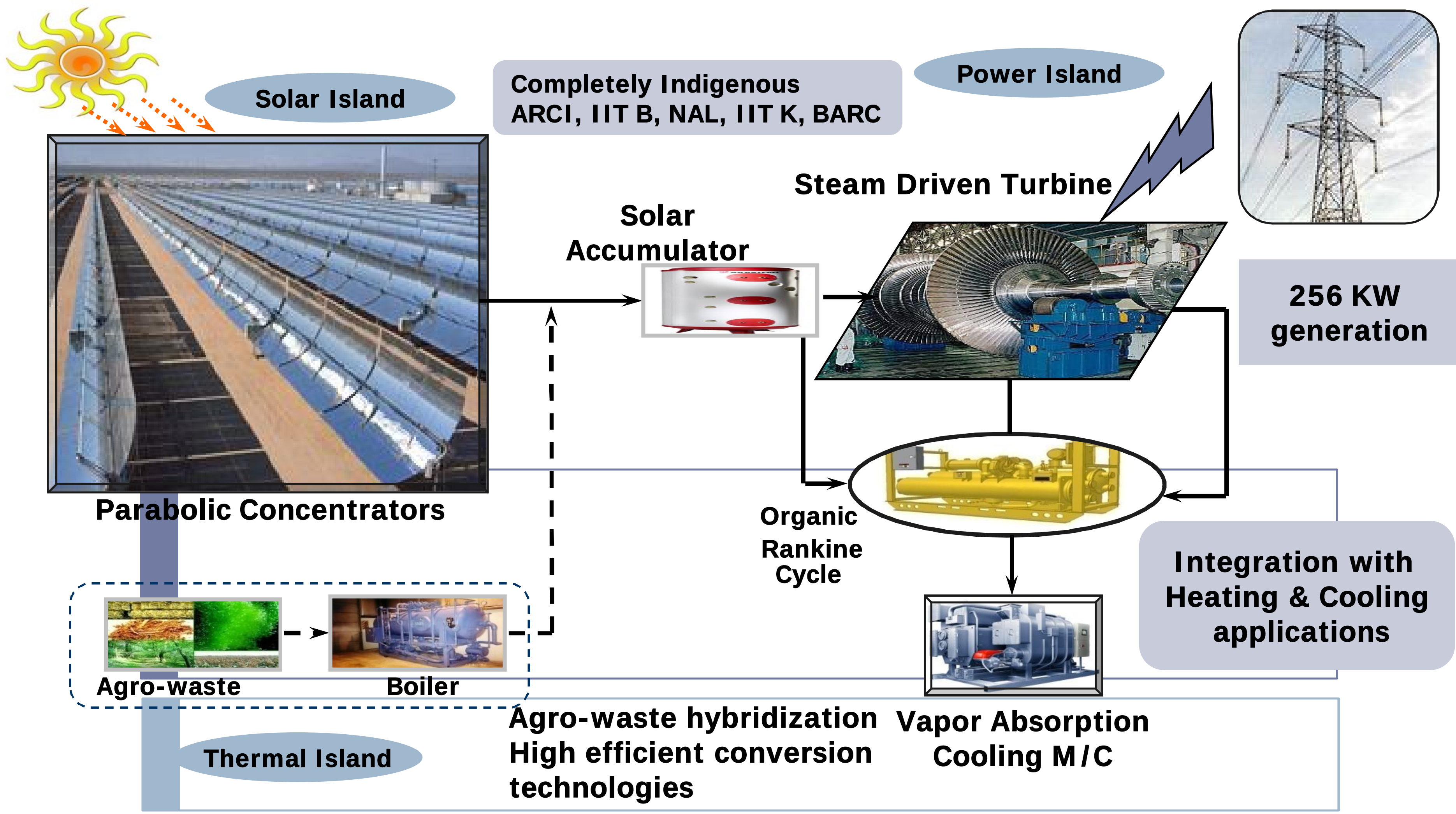
http://acme.in/solar/thermal.html

KG Design Services Private Limited (KGDS)

- Solar thermal research centre in Coimbatore with 1400 m^2 of collection area.
- 45 bar 257 C
- Linear Fresnel Reflector
- Solar Desalination plant
- Solar biomass power plant cum desalination

Source: http://solar.kgisl.com

“Built in India” design

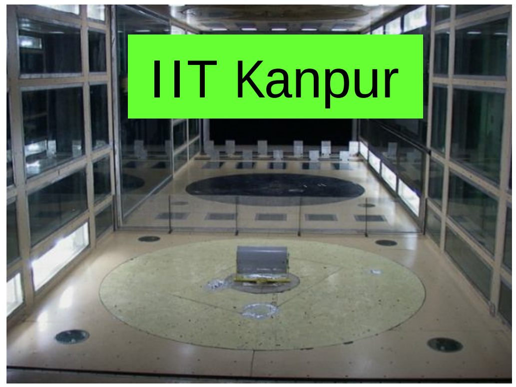


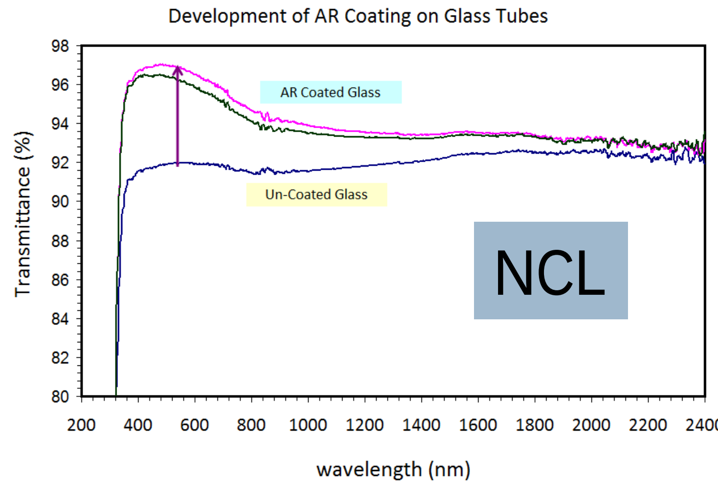
Project approval received in Dec 2009 with a project completion by June 2011. Total cost of R&D project is 9.11 Cr plus O&M costs

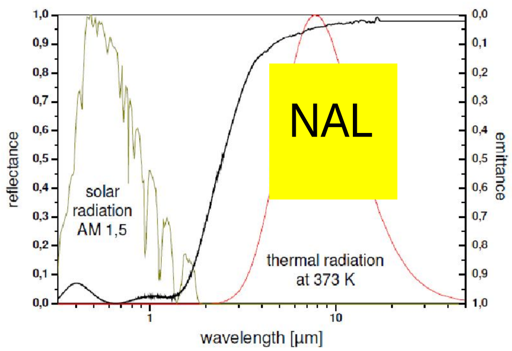
Source: Thermax with permission

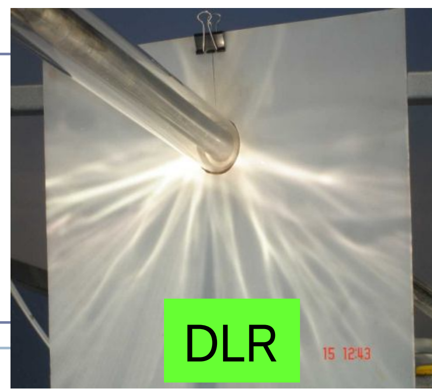
Thermax CLFR design efforts

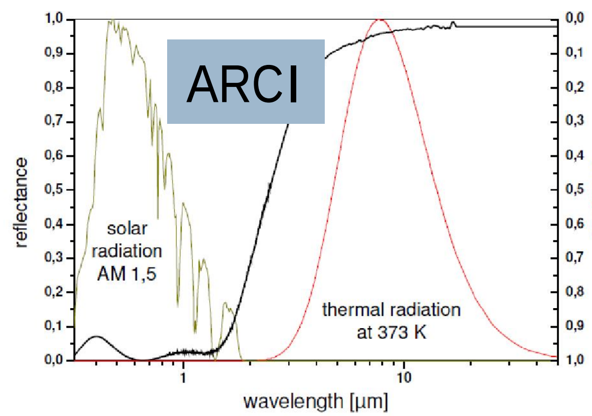
Bridge Technology Gap Through Collaboration



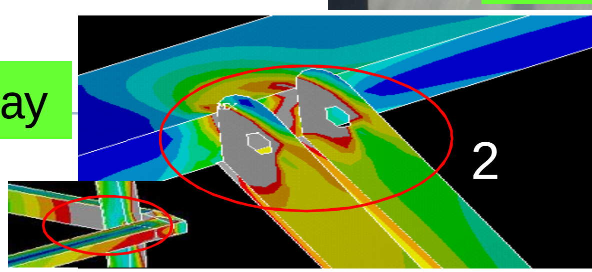








IIT Bombay



Source: Thermax with permission

Point focus fixed to the dish

Maximized intercept factor

Coiled tube cavity absorber

Minimized thermal losses

Automatic two-axes tracking

Facing the Sun, maximum insolation

- $169 m^2$ or $104 m^2$ Arun dish
- Power capacity : 0.5 kW_{peak} / m^2
- Operating hours : 8 to 9 hrs / day
- Daily output : 4 to 4.5 kWh_{th}/day/m^2
- Capital cost : Rs. 21,000 / m^2 (\$400 / m^2)
- Cost Parameter : Rs. 5,000 /(kWh_{th}/day)

Source: Clique Developments Ltd., Mumbai with permission

Solar Thermal Concentrator developed at ATE Enterprise

Process heating market for commercial, small industrial and rural applications (~10 kW$_t$ at 1000 W/m^2 insolation)

- **medium-scale paraboloid dish with 15–30 m^2 aperture area; local vendor base and manufacturing**
- **Direct steam generation using proprietary receiver**
  - **Characterization of thermal performance**
  - **Measurement of mirror reflectivity and effect of ageing**
  - **Remote monitoring**

Source: ATE enterprises with permission

Adhunik Global

- 6kW solar steam power plant
- Fresnel type solar concentrators – 3 of 24m^2 each -area of 96 sq mt. (Design from http://www.solarfire.org/)
- Steam Engine 2 hp to 10 hp

Source: http://www.tinytechindia.com/solar6kwtp.htm

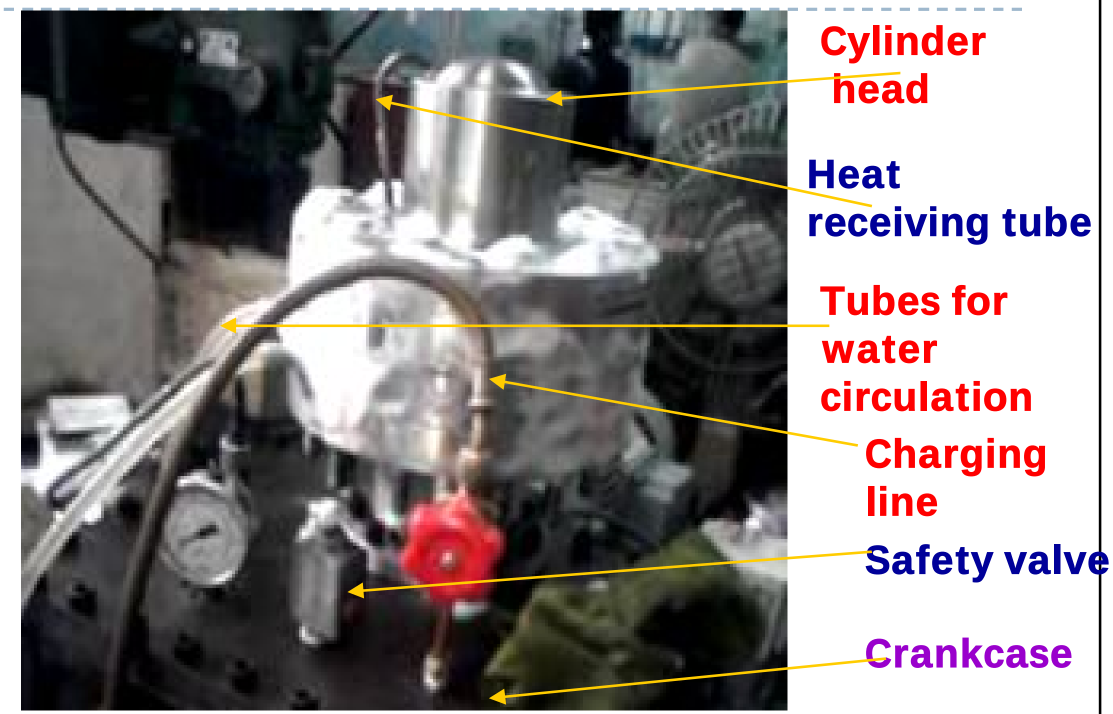
India One Dish Project

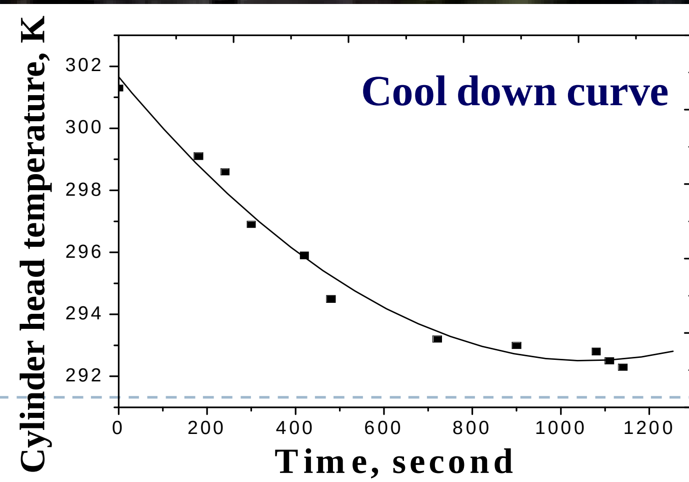
- 60m2 parabolic dish with fixed focus
- Number of dishes : 770 nos. of 60m^2
  Electrical output : 1,0 MW el. (net. 22000 kWh/24hrs)
  Thermal output : 150 MW th. (24hrs)
  Solar field : 25 Acres Abu Road, Rajasthan
  Total mirror area : 45.000 m^2
  Turbine : 1,0 Mw el.

Source: http://www.india-one.net/abouttheproject.html

Design and development of Stirling engine for net 1.5 kW electrical output

- **Stirling engines seems to be viable option**
- **Major heat input should be through gas flame or solar energy**
- **Choice of Capacity for Stirling Engine**
  ~ 96,000 villages to be electrified in India
  - For a group of 3-4 households having enough cattle to supply bio-gas for gas based systems or hybrid systems
  - Use for small capacity pumps for irrigation application
- **Capacity needs to be at least 1.5 kWe**
- **Stirling engines seems to be viable DECENTRALIZED option**





Reliance Power 250 MW Solar Power Plant

Dhursar, Rajasthan

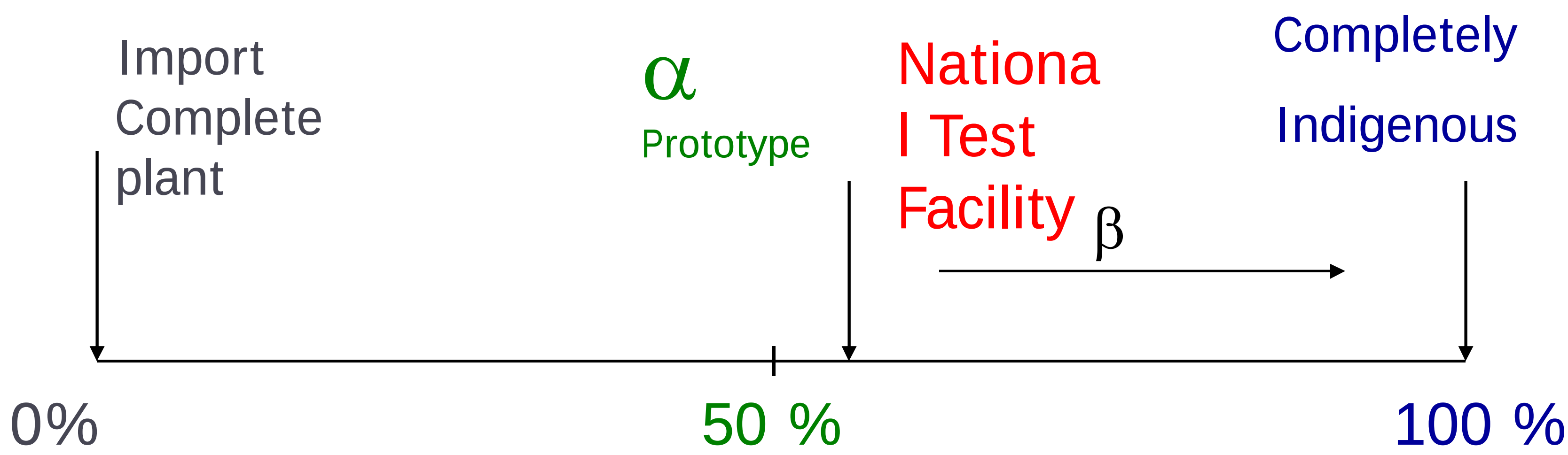
CLFR Technology

2×125 MW

Areva

Target date: May 2013

Concept / Objectives

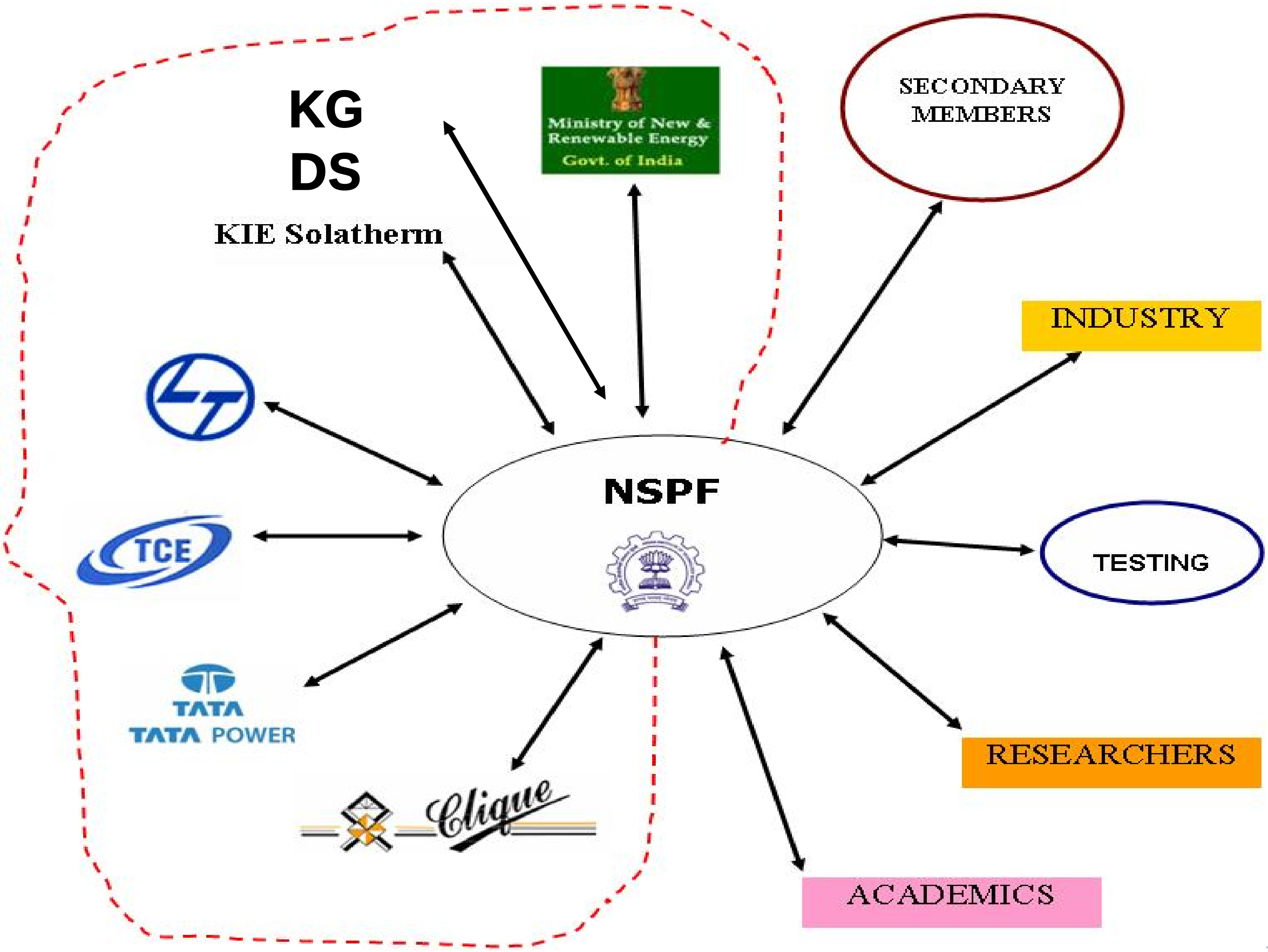


- **1MW Solar Thermal Power Plant**
  - Design & Development of a 1 MW plant.
  - Generation of Electricity for supply to the grid.
  - Development of technologies for component and system cost reduction.

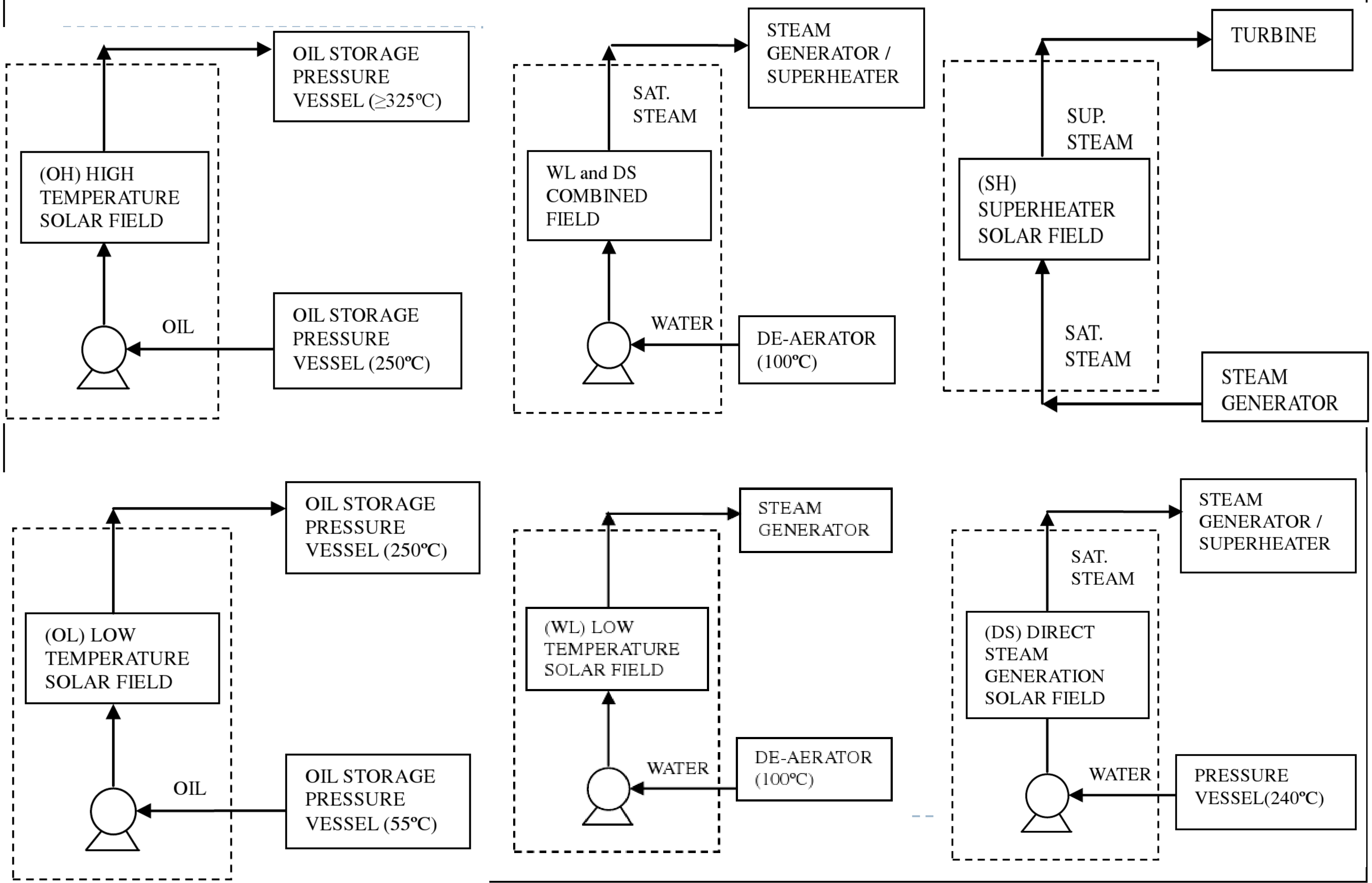
- **National Test Facility**
  - Development of facility for component testing and characterization.
  - Scope of experimentation for the continuous development of technologies.

- **Development of Simulation Package**
  - Simulation software for scale-up and testing.
  - Compatibility for various solar applications.

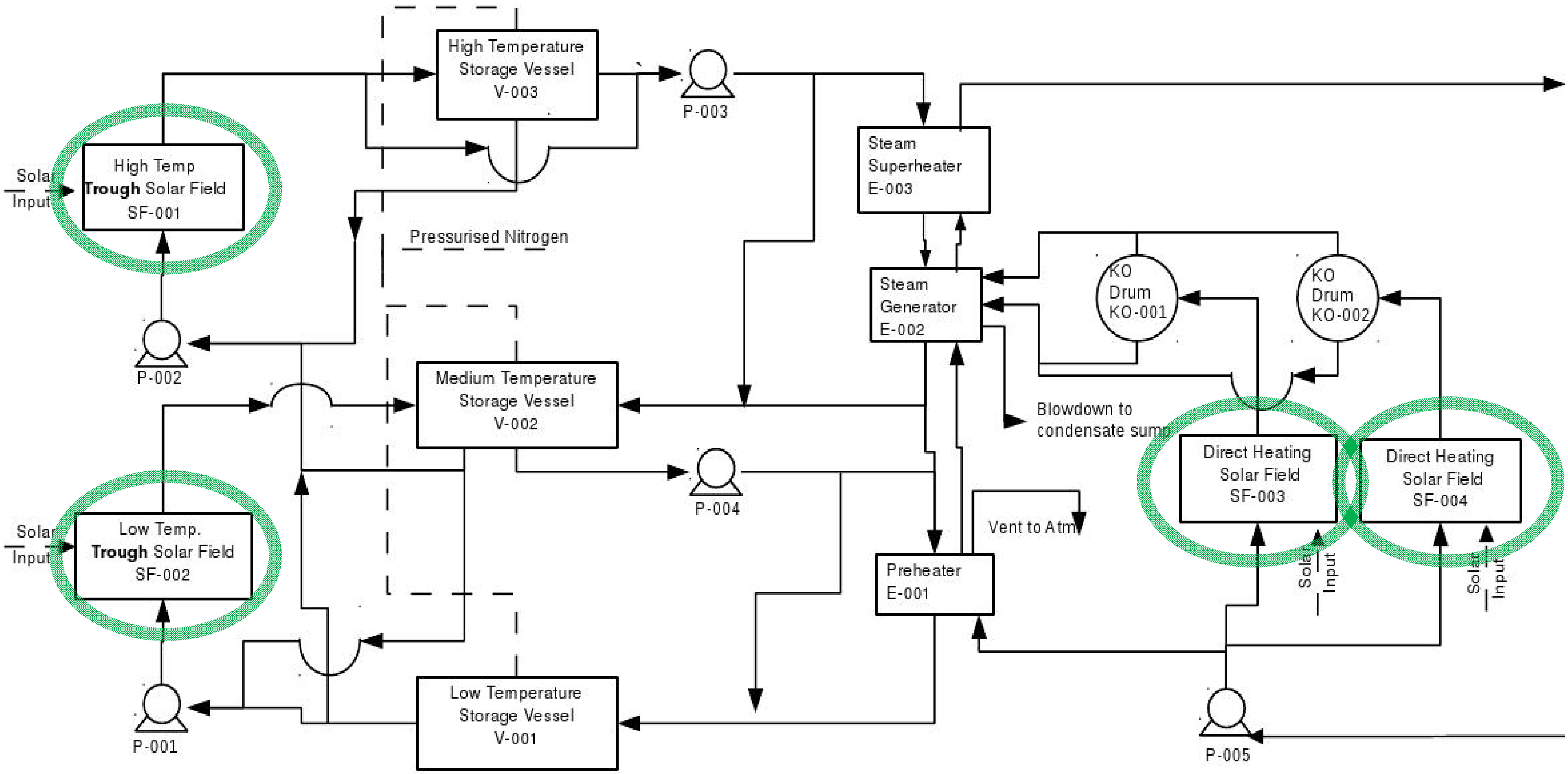
Functioning Mode



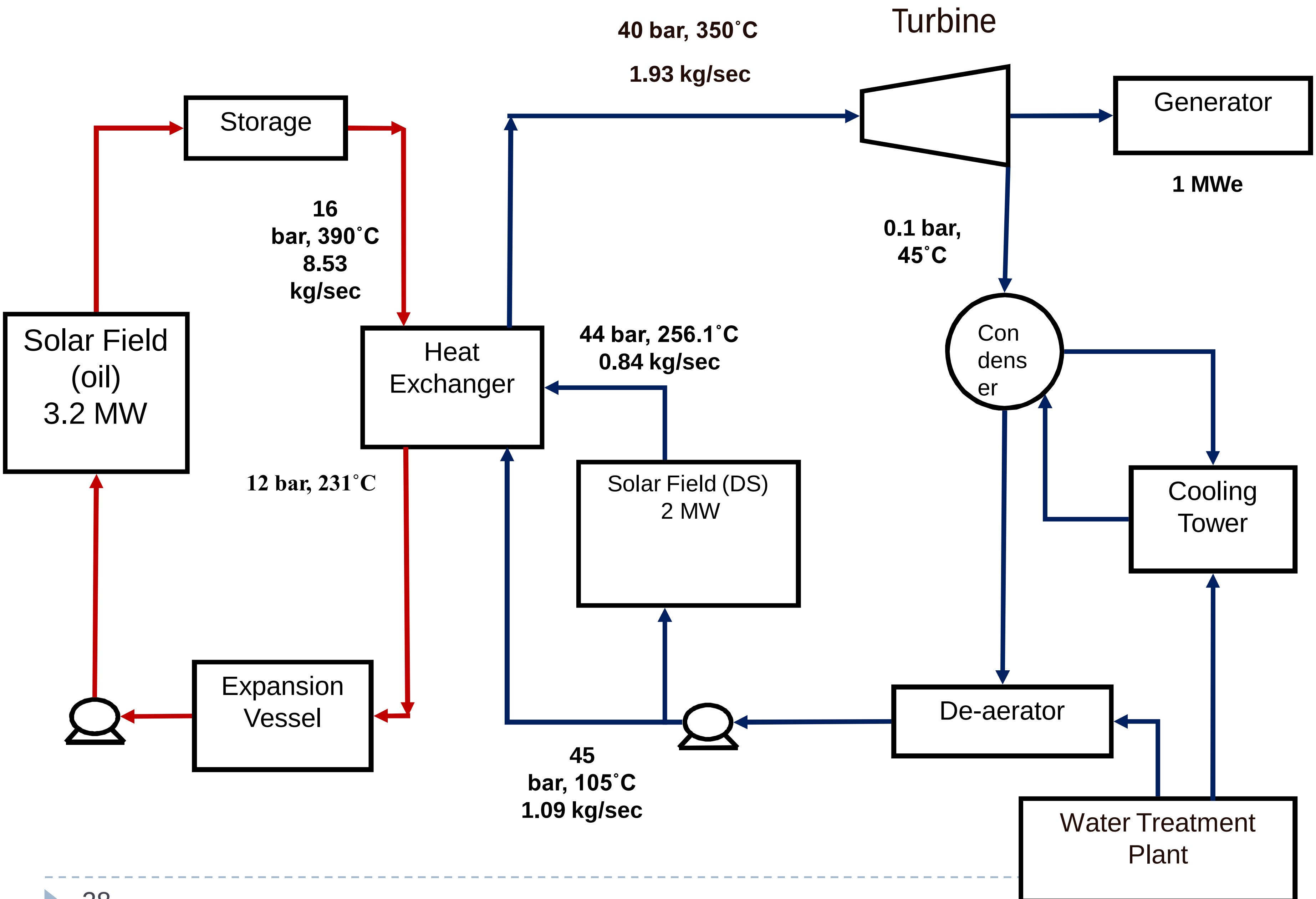
Collector Fields Specified in Tender



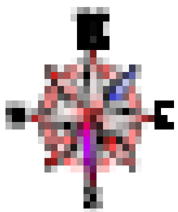
Evolving PFDs

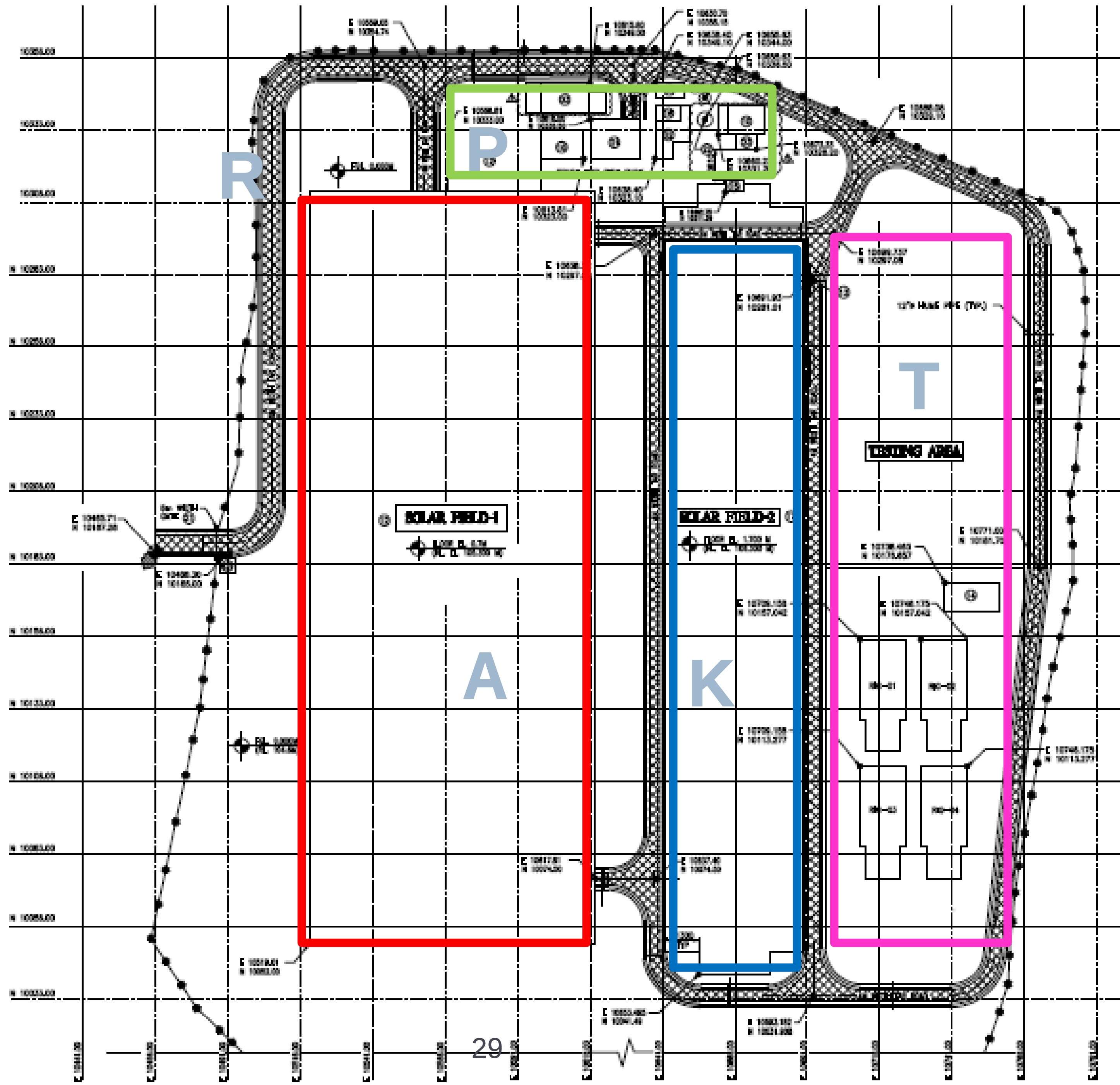


Final (Simplified) Process Flow Diagram

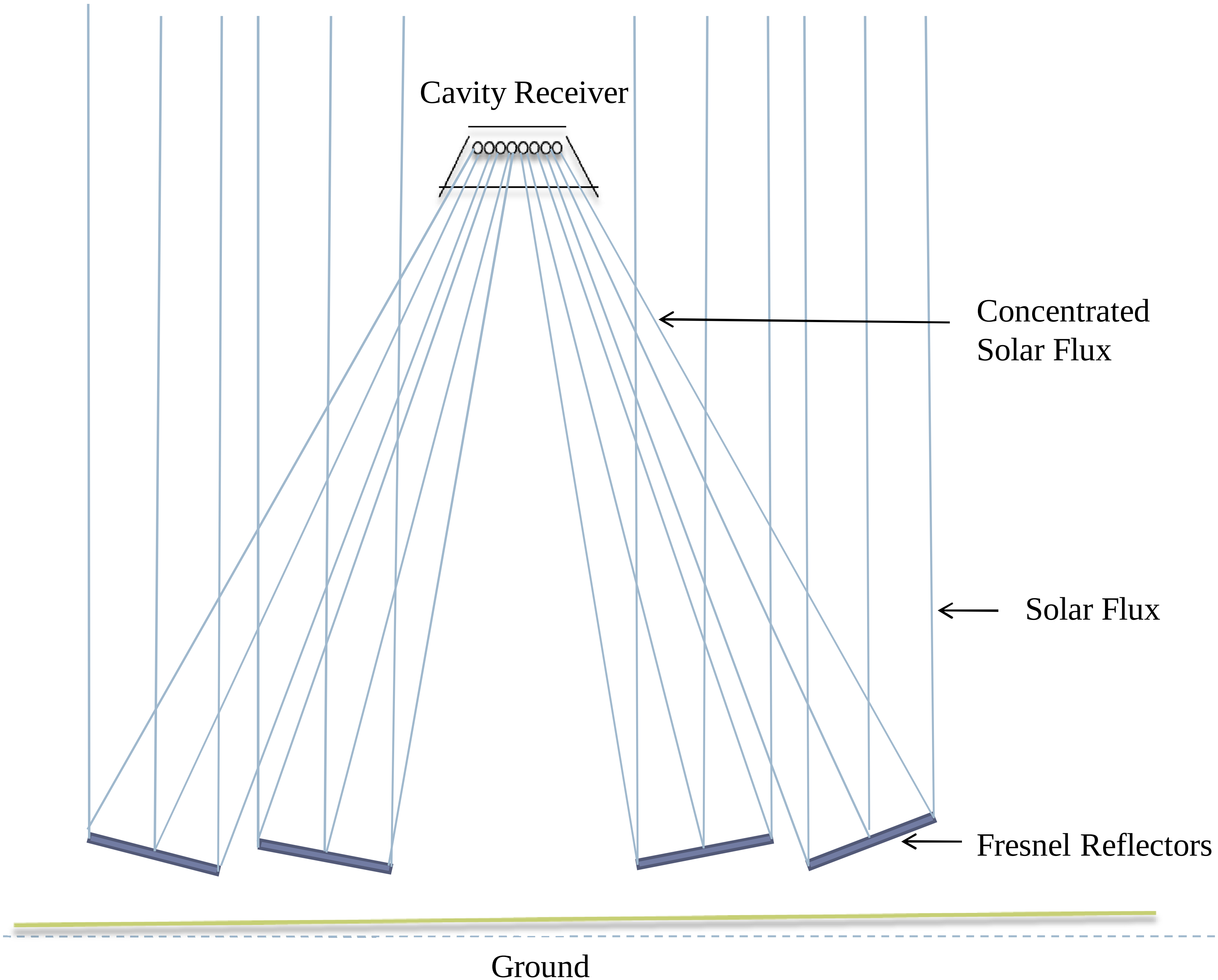


PLOT PLAN





LFR Technology



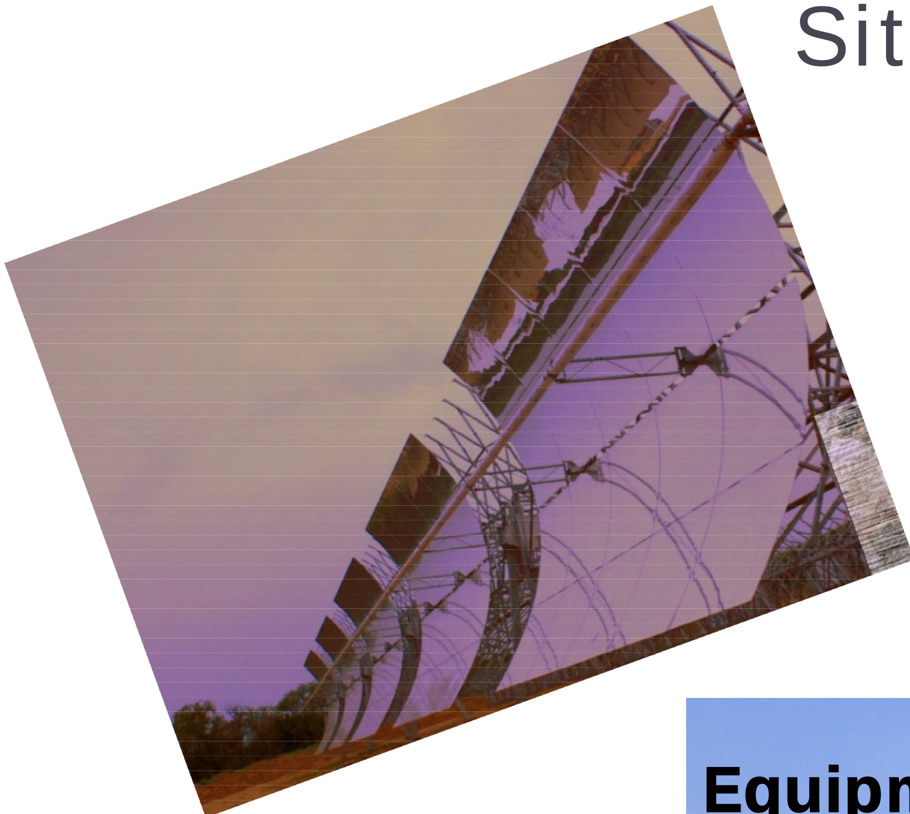
Foundation stone: 10 January, 2010

Tree cutting permission:
August 5, 2010

Soil Testing: October, 2010

Land levelling: November, 2010

Site Photos – PTC Field



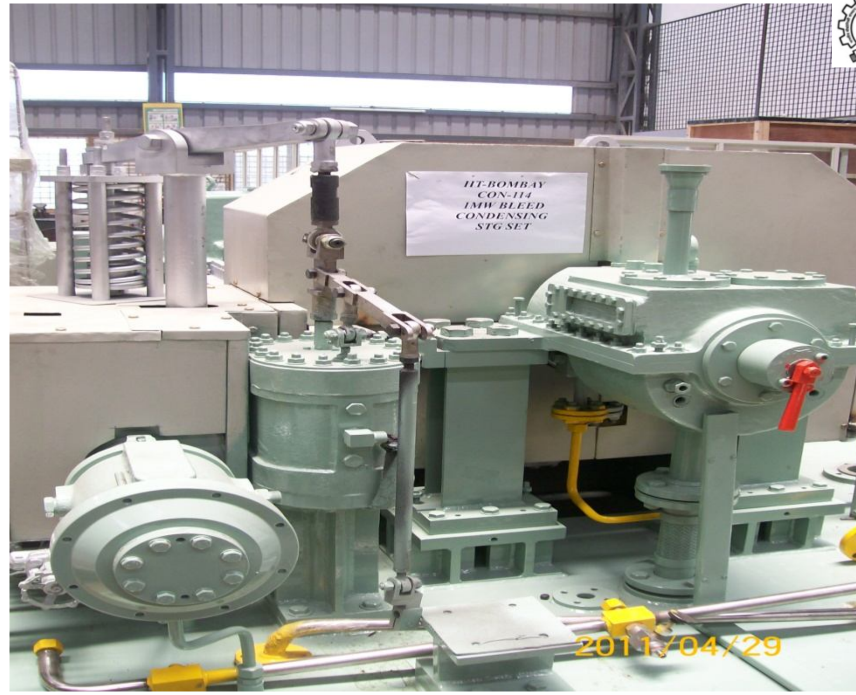
Site Photos – LFR Field

Steam Generation: 28 Sept., 2011

Site Photos – Power Block

Heat Exchangers

Turbine



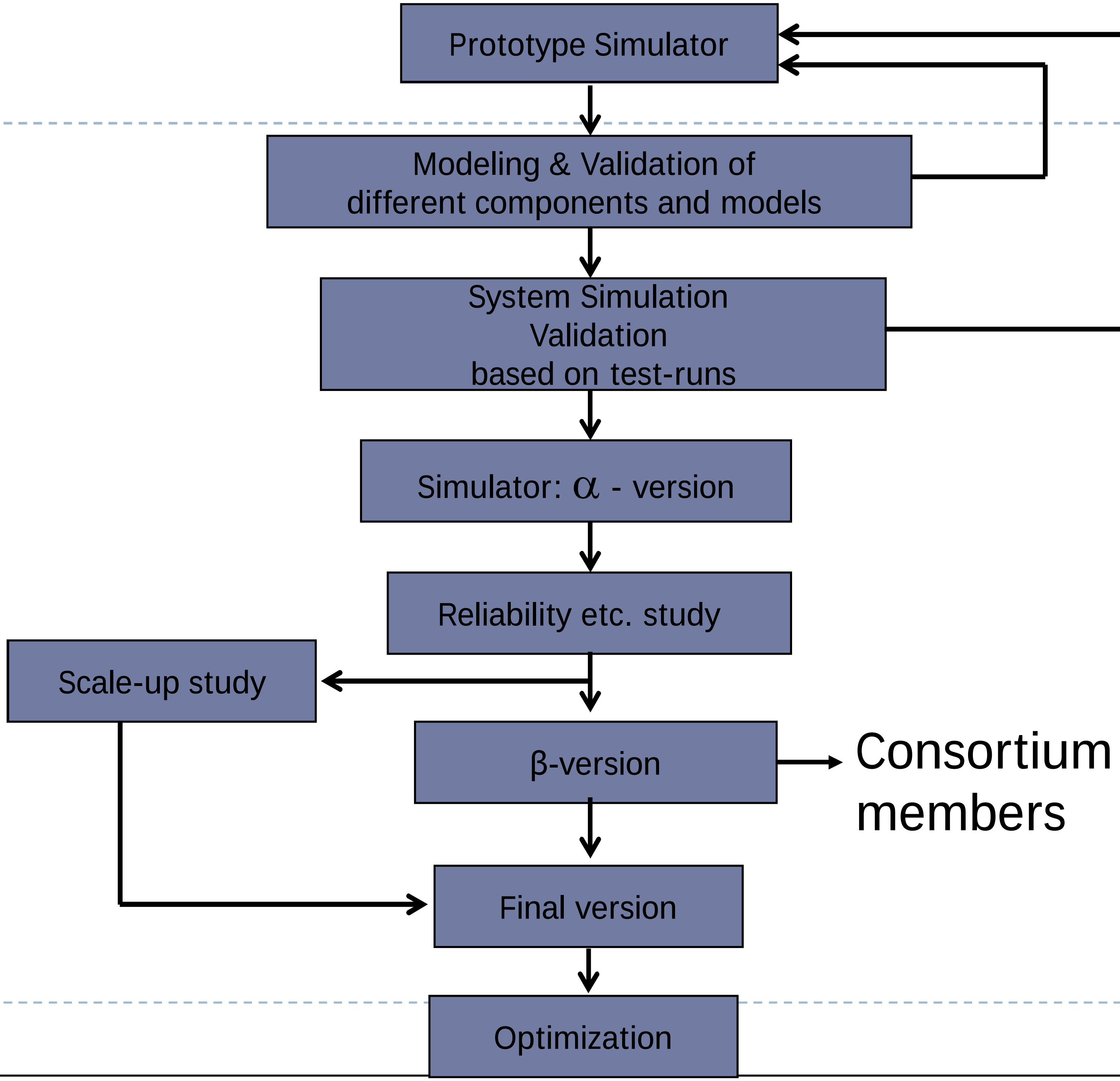
Generator

Cooling Tower

Schematic of Solar Power Plant Simulator

General User Inputs	
Solar Models	site data – lat., long., insolation, temperature wind speed, rainfall Data library, interpolation modules, empirical
Fluid Models	Fluid properties – water, thermic fluids, etc. Library of fluid properties
Equipment Models	Characteristic models – solar collectors, pumps, heat exchangers, turbines, etc. [e.g., collector η = f (m_{in}, T_{in}, $I_{T/B}$, V_{wind})]
Flow sheeting	User defined connectivity for equipment through GUI. Alternative configurations can be studied.
Equation builder & Solver	Based on user defined PFD – mathematical models User defined time steps, time horizon. Pseudo steady State simulation – sequential modular approach
Simulation output	System performance including cost of overall system

Simulator Development Steps



Achieved Outputs: Simulator Facility

Solar Thermal Simulator

Preliminary Version v 0.0

Open Sample Process Flow Diagram

[Sample PFD1] (Direct Steam Generation Power Plant)

[Sample PFD2] (Thermic Fluid based Indirect Steam Generation Power Plant)

[Sample PFD3] (Hybrid Solar Thermal Power Plant)

[Sample PFD4] (Thermic Fluid based Indirect Steam Generation Power Plant with Regeneration)

[Sample PFD5] (Thermic Fluid based Indirect Steam Generation Power Plant with Reheat : Nevada Solar One Plant)

[Sample PFD6] (Thermic Fluid based Indirect Steam Generation Power Plant with Reheat : Solnova Plant)

Open existing Process Flow Diagram   Create Process Flow Diagram

Getting Started

- Open any of the six sample process flow diagram for steady state simulation.
- Double click the equipment and stream node to know its parameters and to make changes.
- Parametric study can be done by changing the system parameters, such as, location, stream parameters, control variable, equipment model parameters, etc.
- Save the file (even if no changes are made) and click 'Run Simulation' for getting results.
- The results will be displayed in tabular format.

** Usage of this Software is governed by the licence agreement*

Preliminary Version :
released on <u>25th, July 2011</u>

Achieved Outputs: Simulator Facility

➢ The key features of the Preliminary Version:

- Simulation of fixed configurations of the systems
- Graphical user interface for data input and output
- Manual as well as database entry of climatic and equipment parameters
- User defined time step and time horizon for the simulation
- Display of the results in tabular form
  - output of all equipment for each time step, annual power generation, capital cost, cost of energy
- Parametric study by changing the system parameters
  - location, equipment model parameters, stream parameters, control variables

Distribution of user category

	No. of users
Institute and University	380
Industry and Organisation	560
Others	90
Total (as on 16th May 2012)	1030

Summary:

- **22 different countries (other than India):**
  - **Austria, Australia, Belgium, Canada, Cameroon, China, Cyprus, Denmark, Germany, Iran, Iraq, Malaysia, Mexico, Morocco, Netherlands, Pakistan, Palestine, Somalia, Spain, Suda n, UAE and USA**
- **140 different Institutes and Universities**
  - **In India->** **IITs, IIM, NITs, Amity University, ANNA University, BITS, Delhi University, Indian School of Mines, Institute for Plasma Research, JADAVPUR UNIVERSITY, JNTU, Hyderabad, Mewar University, Nirma University, NITIE Mumbai, P.S.V college of Engg. and Tech., Panjab University, PDPU Gandhinagar , PSG College of Tech., Pune University, Vellore Institute of Technology, and Others**
  - **Outside India->** **Austrian Institute of Technology-Austria, Carnegie Mellon University-USA, McMaster Uni.-Canada,Chinese Academy of Sciences-China, University of Illinois-USA, Universidad de Valladolid-Spain, University of Copenhagen-Denmark, and Others**

Distribution of user category

- **155 different Industries and Organisation :**
  - **In India->** Abener Engineering, Adani Infra India Ltd., BARC, BHEL, Brahma Kumaris, Central Electricity Regulatory Commission, Central Power Research Institute, Clique Developments Ltd., Cummins Research & Technology, Deloitte Touche Tohmatsu, Engineers India Ltd., Entegra Ltd., GAIL, GM, GERMI, Godavari Green Energy Ltd., KG Design Services Pvt. Ltd, Lanco Solar Energy Pvt . Ltd., L & T, Maharishi Solar Technology Pvt. Ltd., Mahindra & Mahindra, Maxwatt Turbines Pvt. Ltd., MNRE, MWCorp, National Power Training Institute, NPCIL, Pryas, Reliance Industries, SAIL, Siemens Ltd., Solar Energy Center, SPRERI, Sujana Energy, Tata Power, Thermax Ltd., Vedanta Resources, Welspun, and Others
  - **Outside India->** DLR-Germany, Dubai Electricity and Water Authority-UAE, Eco Ltd.-Belgium, ELIASOL-USA, Fichtner-Germany, International Renewable Energy Agency-UAE, Shell Global Solutions International–Netherlands, Sol Systems-USA, Suntrace GmbH-Germany, and Others

Added Features of α-version

- Scope for user defined plant configurations
  - Flexibility to simulate user defined small subset of a complete plant or a complete plant
- Addition of equipment like pipe element, auxiliary boiler, pressure reducing valve and storage vessel
- Database as well as manual entry of cost co-efficient
- Facility of exporting results to MS Excel file

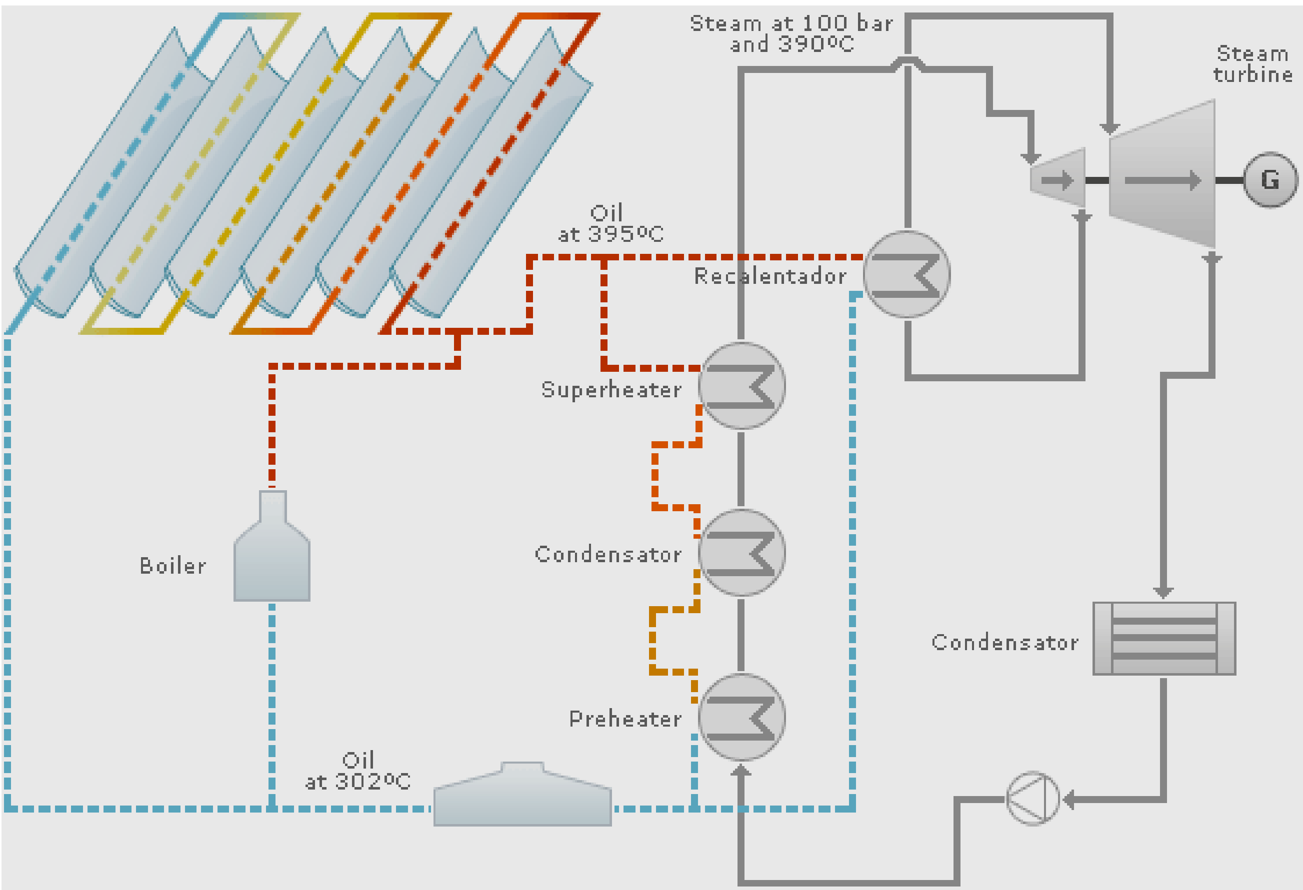
Potential users are identified for the α-version

Simulation of user defined Process Flow Diagram

Plant: Solnova (Abengoa Solar)

Location: Spain

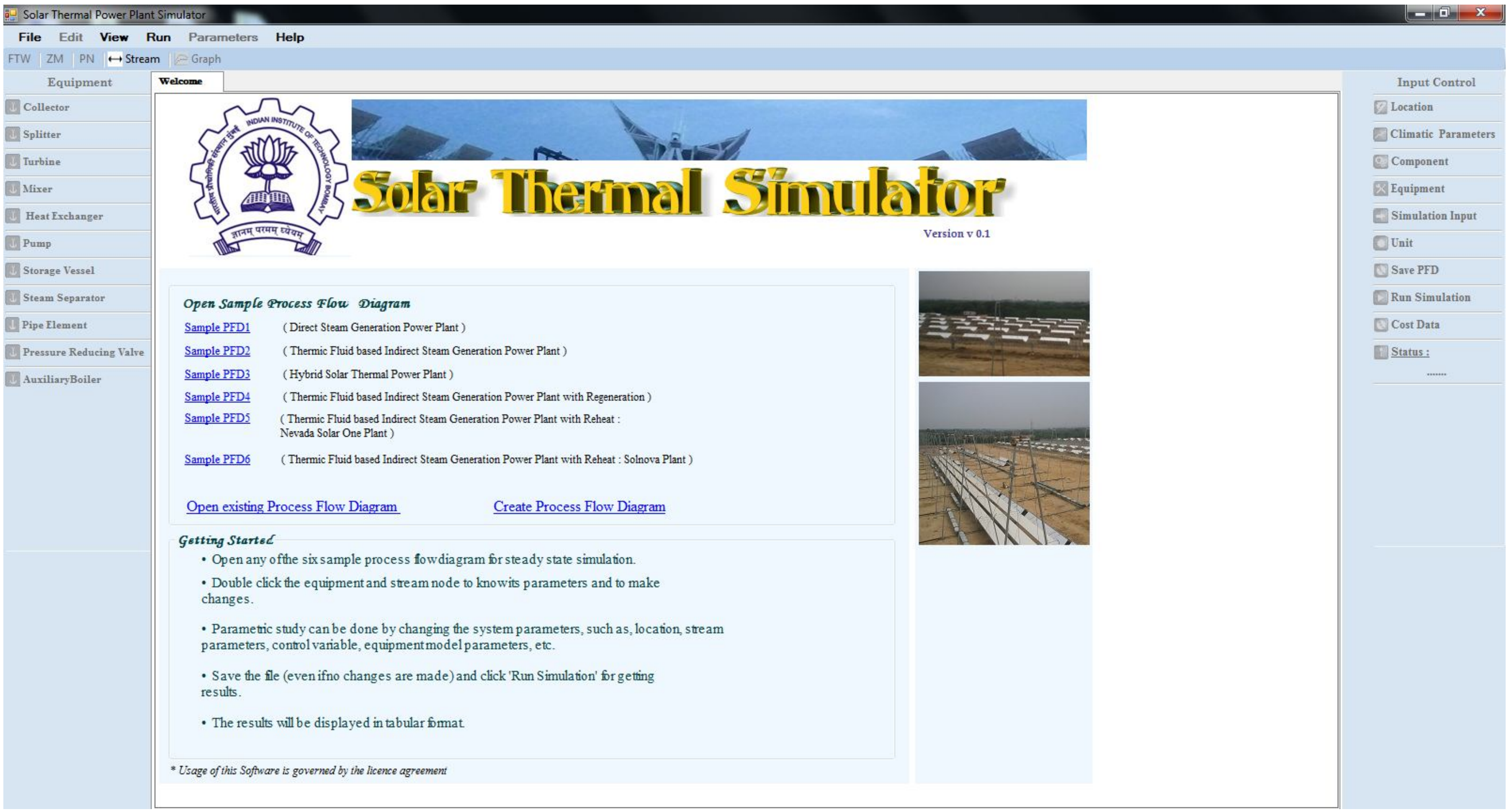
Capacity: 50MW



Ref.: http://www.abengoasolar.com

Steps to be followed for the Simulation

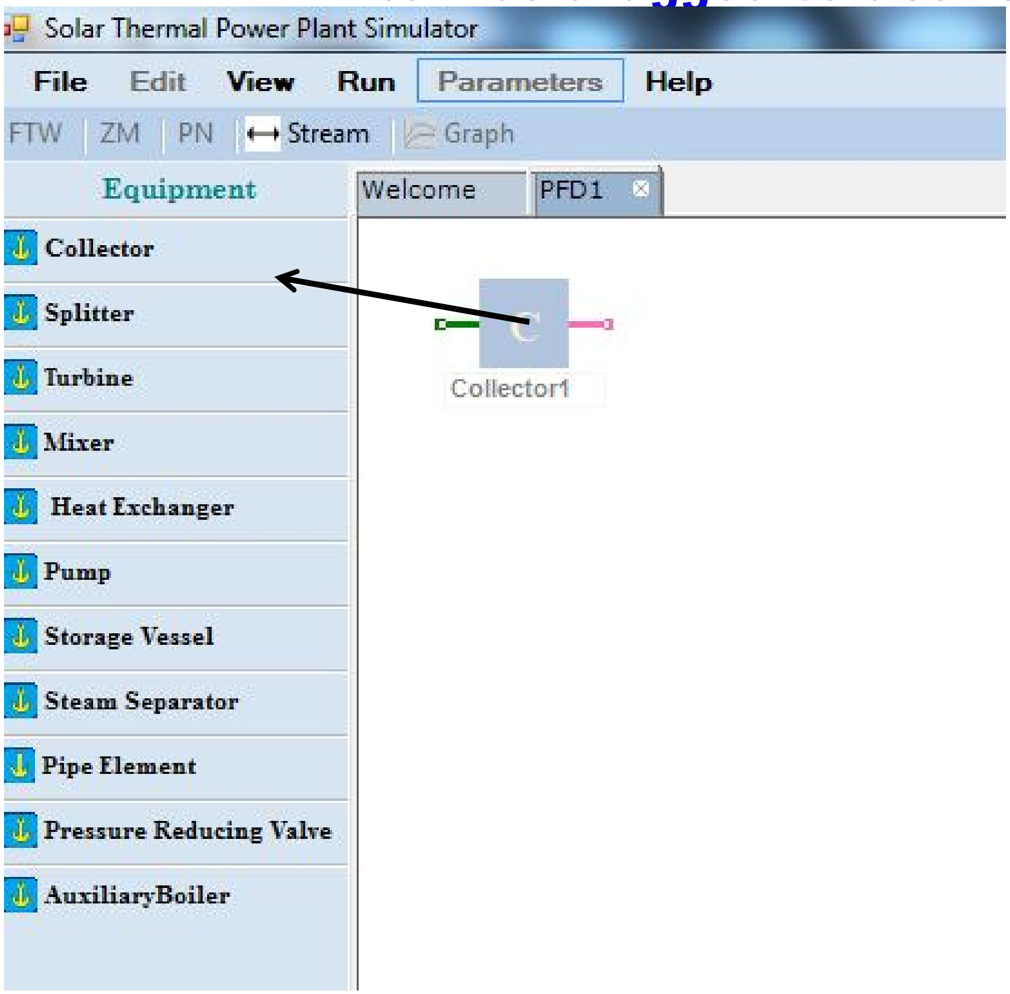
- **Select any of the six PFD for the simulation or Open/Create Process Flow Diagram**



- How to Create Process Flow Diagram

Step 1: Select equipment to be entered from the equipment

Step 2: Equipment will appear on PFD generation area which can be dragged to desired location

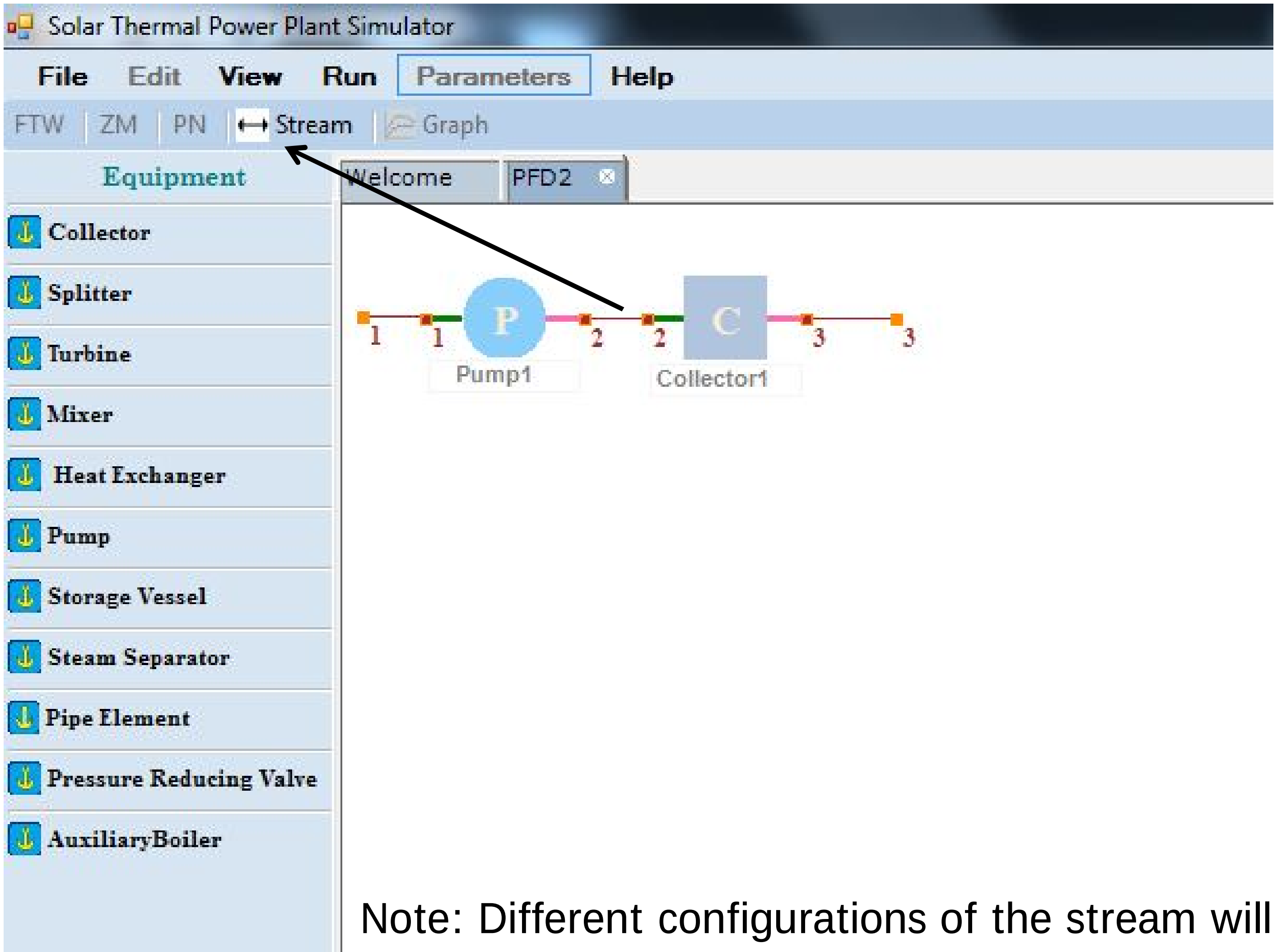


- Input node: Green colour
- Output node: Pink colour
- The option of deleting the equipment and reversing the node is available on right click

Note: In case of heat exchanger, orange node is hot stream input node and blue node is cold stream input node

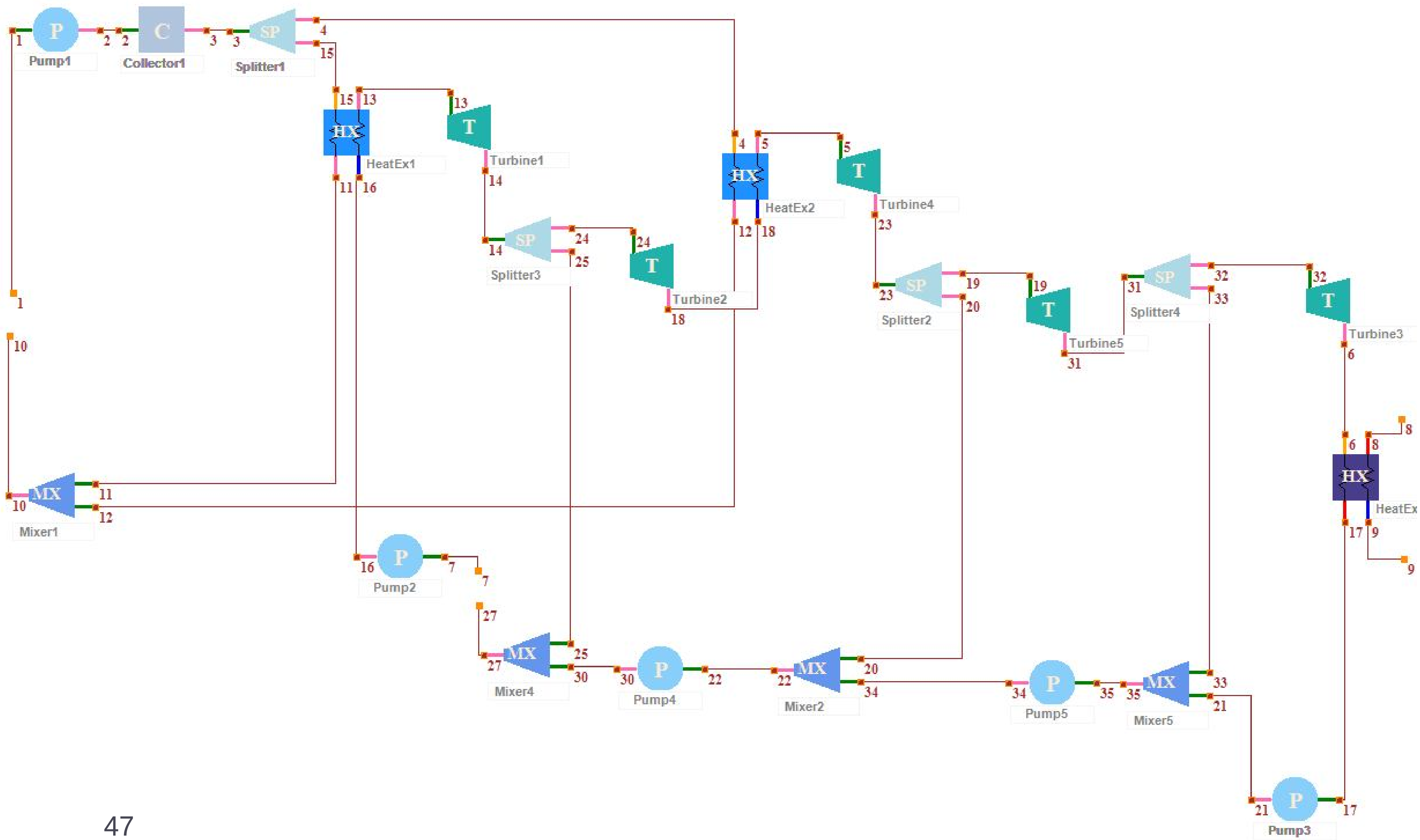
- **How to Create Process Flow Diagram**

Step 3: The equipment can be linked through stream and any PFD can be generated for the simulation

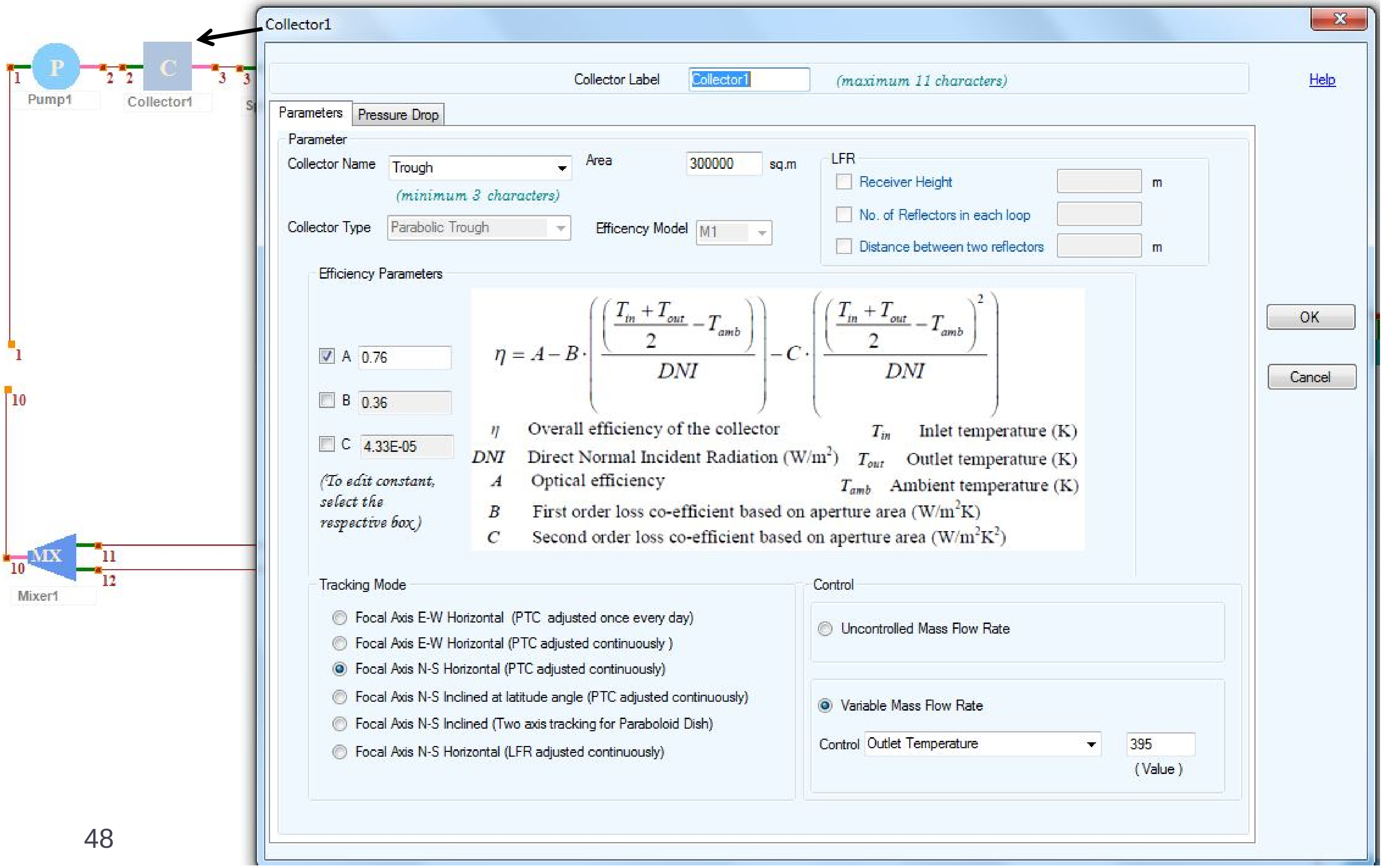


Note: Different configurations of the stream will be listed on right click of stream node

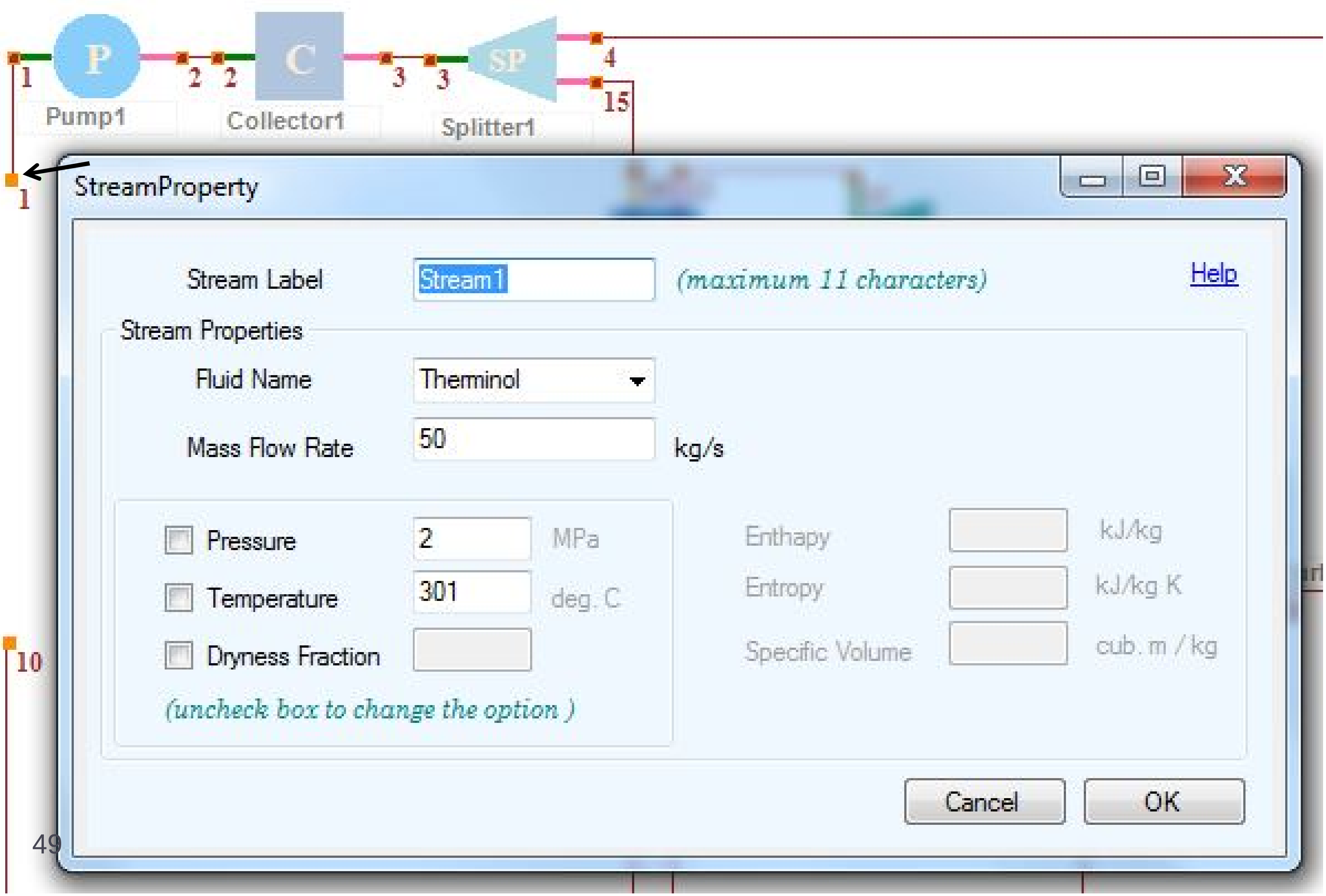
Process Flow Diagram of Solnova Plant for 100% Solar Load



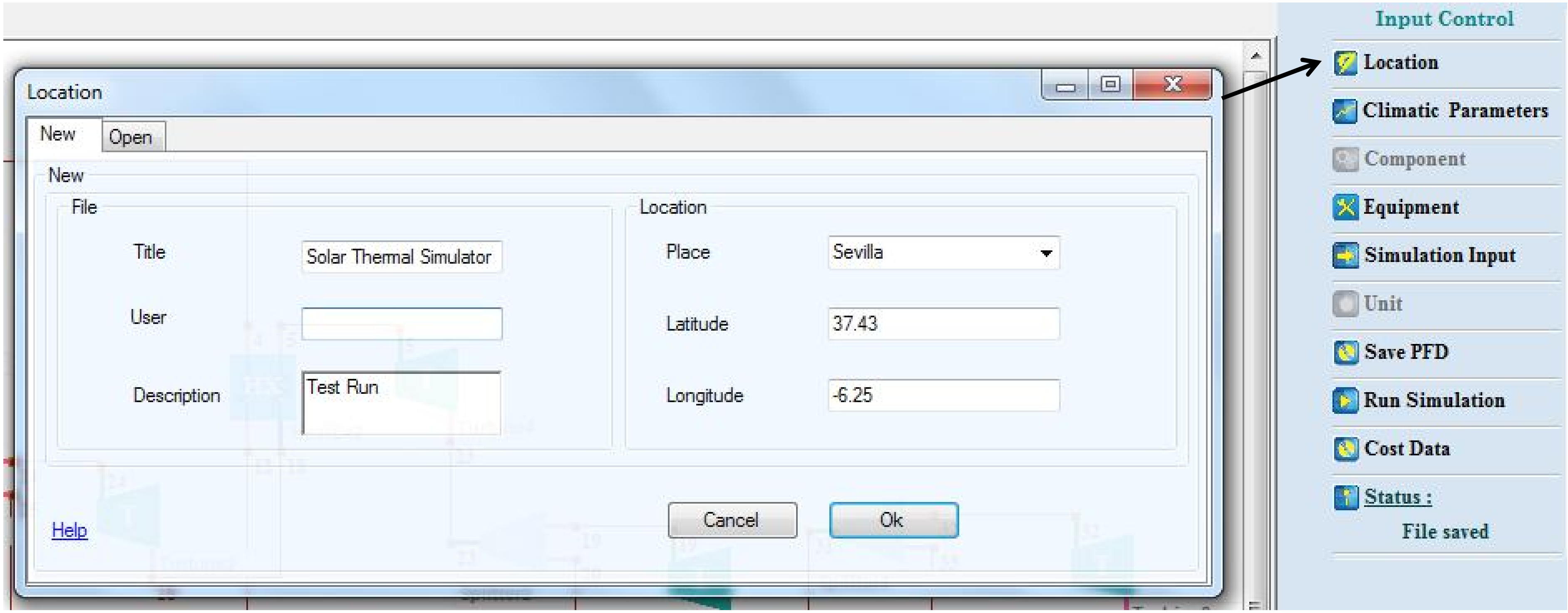
- Double click the equipment to enter its parameters and to make changes



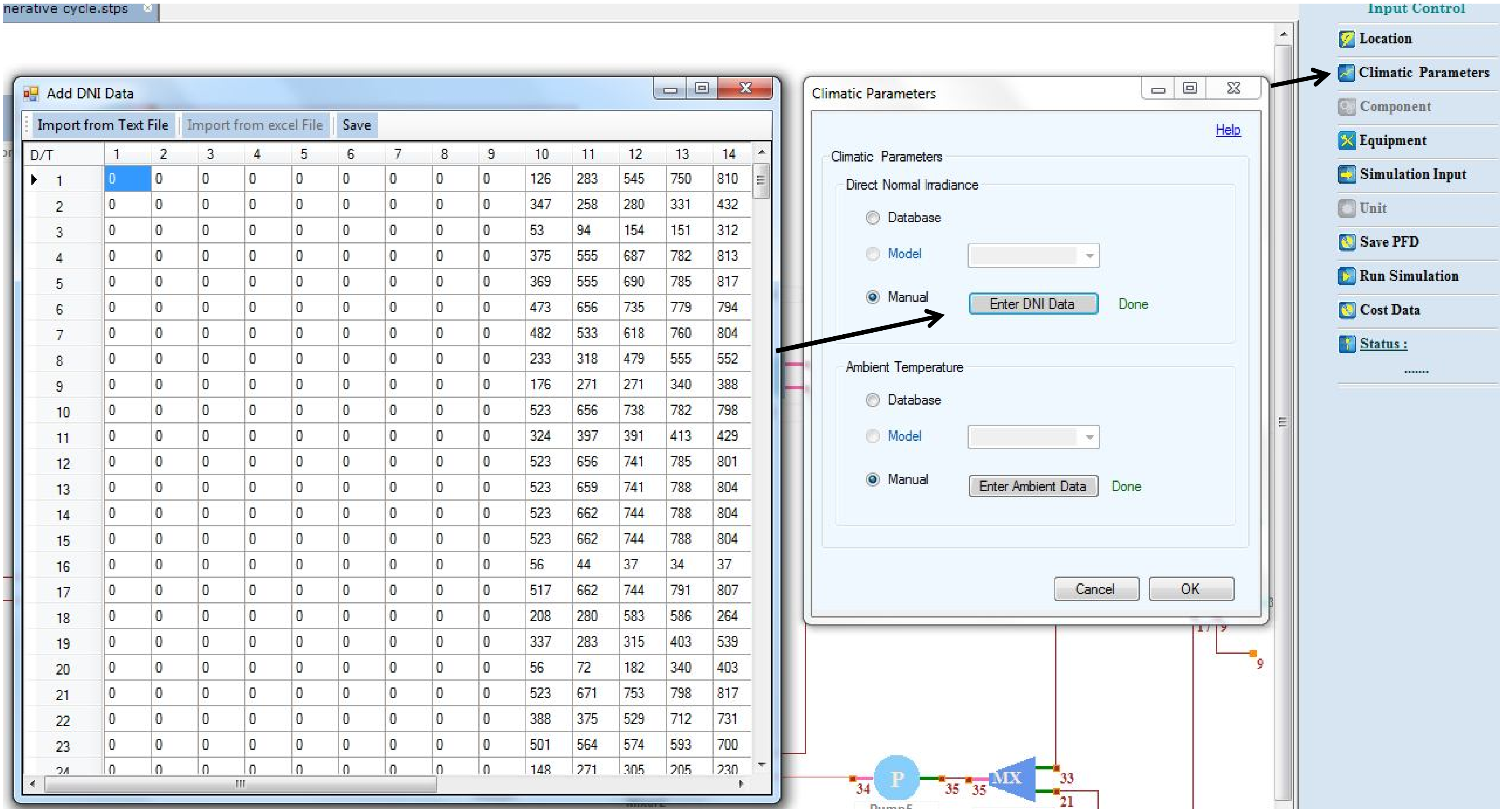
- **Double click the stream node to specify the guess values of stream parameters**



- **Location can be entered/changed from 'Location' Input Window**
    - **Database or Manual entry**



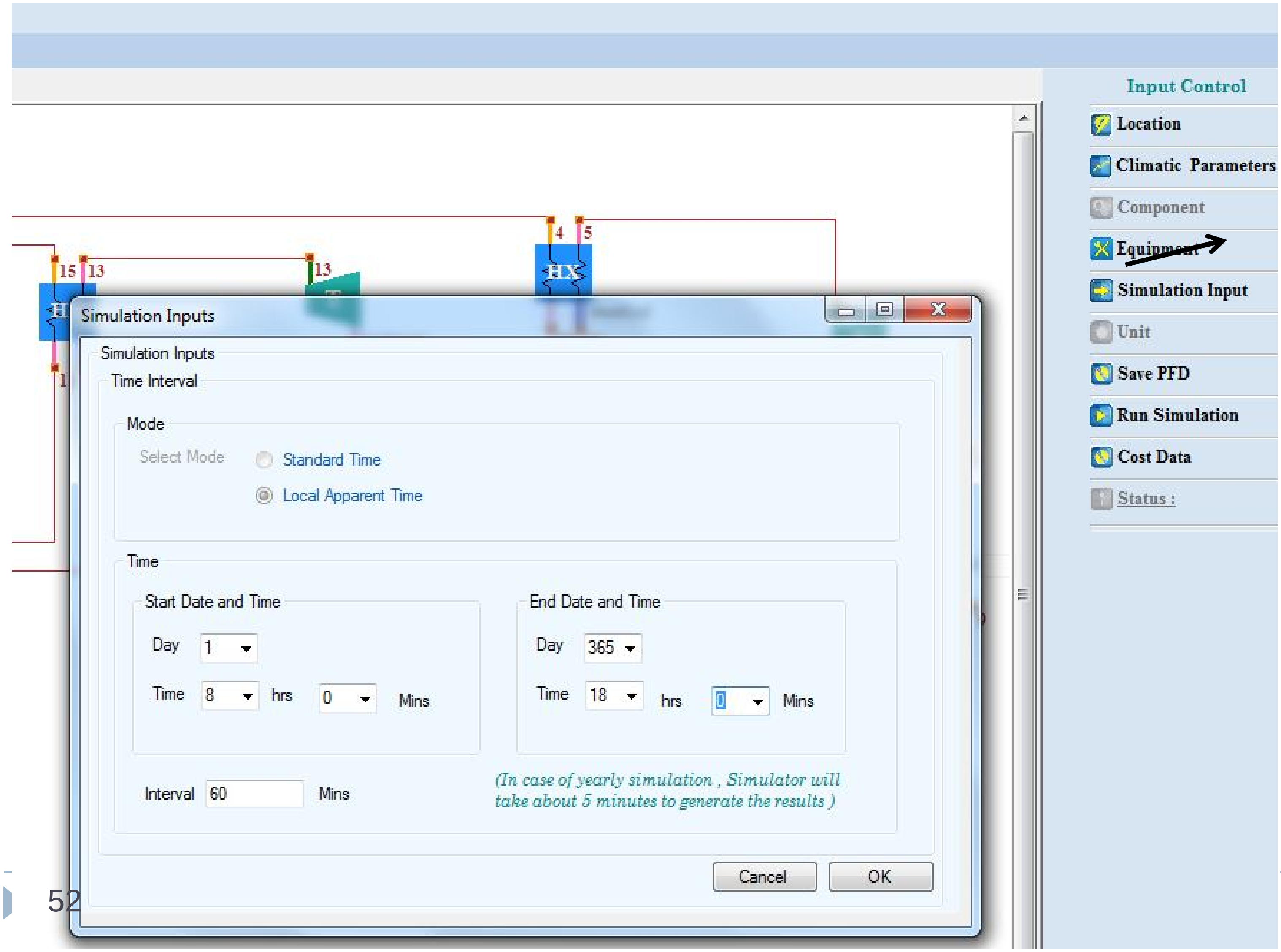
- **Climatic Parameters can be changed from ‘Climatic Parameters’ Input Window: Database or Manual entry**



D/T	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	0	0	126	283	545	750	810
2	0	0	0	0	0	0	0	0	0	347	258	280	331	432
3	0	0	0	0	0	0	0	0	0	53	94	154	151	312
4	0	0	0	0	0	0	0	0	0	375	555	687	782	813
5	0	0	0	0	0	0	0	0	0	369	555	690	785	817
6	0	0	0	0	0	0	0	0	0	473	656	735	779	794
7	0	0	0	0	0	0	0	0	0	482	533	618	760	804
8	0	0	0	0	0	0	0	0	0	233	318	479	555	552
9	0	0	0	0	0	0	0	0	0	176	271	271	340	388
10	0	0	0	0	0	0	0	0	0	523	656	738	782	798
11	0	0	0	0	0	0	0	0	0	324	397	391	413	429
12	0	0	0	0	0	0	0	0	0	523	656	741	785	801
13	0	0	0	0	0	0	0	0	0	523	659	741	788	804
14	0	0	0	0	0	0	0	0	0	523	662	744	788	804
15	0	0	0	0	0	0	0	0	0	523	662	744	788	804
16	0	0	0	0	0	0	0	0	0	56	44	37	34	37
17	0	0	0	0	0	0	0	0	0	517	662	744	791	807
18	0	0	0	0	0	0	0	0	0	208	280	583	586	264
19	0	0	0	0	0	0	0	0	0	337	283	315	403	539
20	0	0	0	0	0	0	0	0	0	56	72	182	340	403
21	0	0	0	0	0	0	0	0	0	523	671	753	798	817
22	0	0	0	0	0	0	0	0	0	388	375	529	712	731
23	0	0	0	0	0	0	0	0	0	501	564	574	593	700
24	0	0	0	0	0	0	0	0	0	148	271	305	205	230

- **Enter Simulation Inputs:**

User defined *Time Step* and *Time Horizon* for the simulation



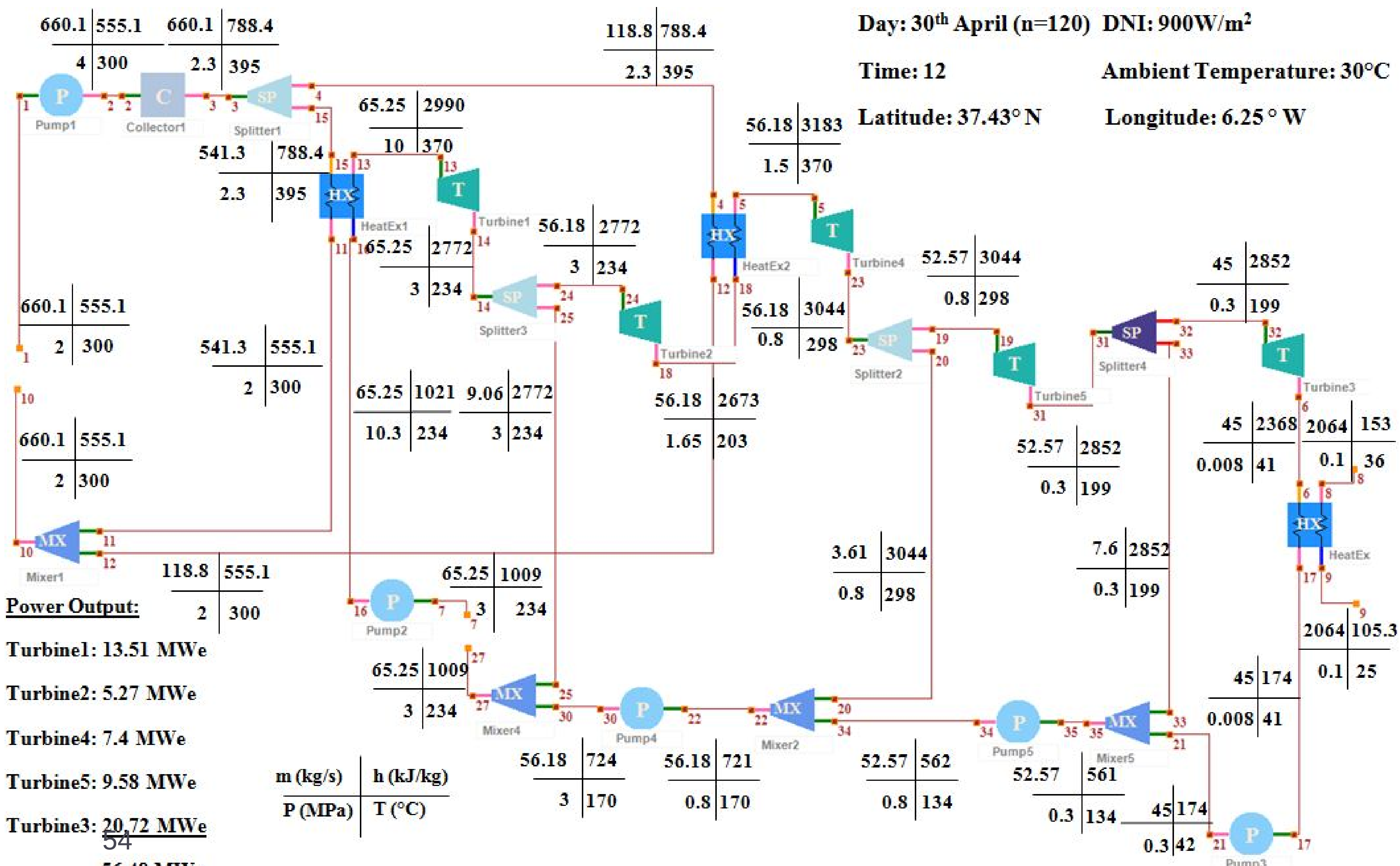
- **Save the file clicking ‘Save PFD’**
- **Click ‘Run Simulation’ for getting results**
- **The results (output parameters of all the equipments) will be displayed in tabular format**
- **Results can be exported to MS Excel file**

Result

Export Result to Excel File | *Solar Thermal Power Plant Simulator , IIT Bombay*

Day	Time	Declination	Hour Angle	CosZenithAngle	Ambient Temperature (deg. C)	DNI (W/m^2)	Beam Radiation (W/m^2)	Pump:-Pump1:-P1	W_in:P1 (kW)
365	9	-23.09	45	0.278	11.7	0	0		165
365	10	-23.09	30	0.394	12	381	150.2		415
365	11	-23.09	15	0.467	12.8	555	259.3		649.8
365	12	-23.09	0	0.492	14.2	684	336.6		812.6
365	13	-23.09	-15	0.467	15.8	776	362.5		1020.6
365	14	-23.09	-30	0.394	17.2	804	317		1234.4
365	15	-23.09	-45	0.278	18.4	769	213.9		1363.9
365	16	-23.09	-60	0.127	19.2	671	85.1		1305.3
365	17	-23.09	-75	-0.049	19.2	0	0		165
365	18	-23.09	-90	-0.238	18.4	0	0		165
Total Heat Gain of Collector (MWh)	133160.65								
Net Power Output (MWh)	89359.94								
Turbine Output (MWh)	99605.98								
Pump Input (MWh)	10245.72								

Heat and Mass Balance Diagram of Solnova Plant at 100% Solar Load



Power Output:

Turbine1: 13.51 MWe

Turbine2: 5.27 MWe

Turbine4: 7.4 MWe

Turbine5: 9.58 MWe

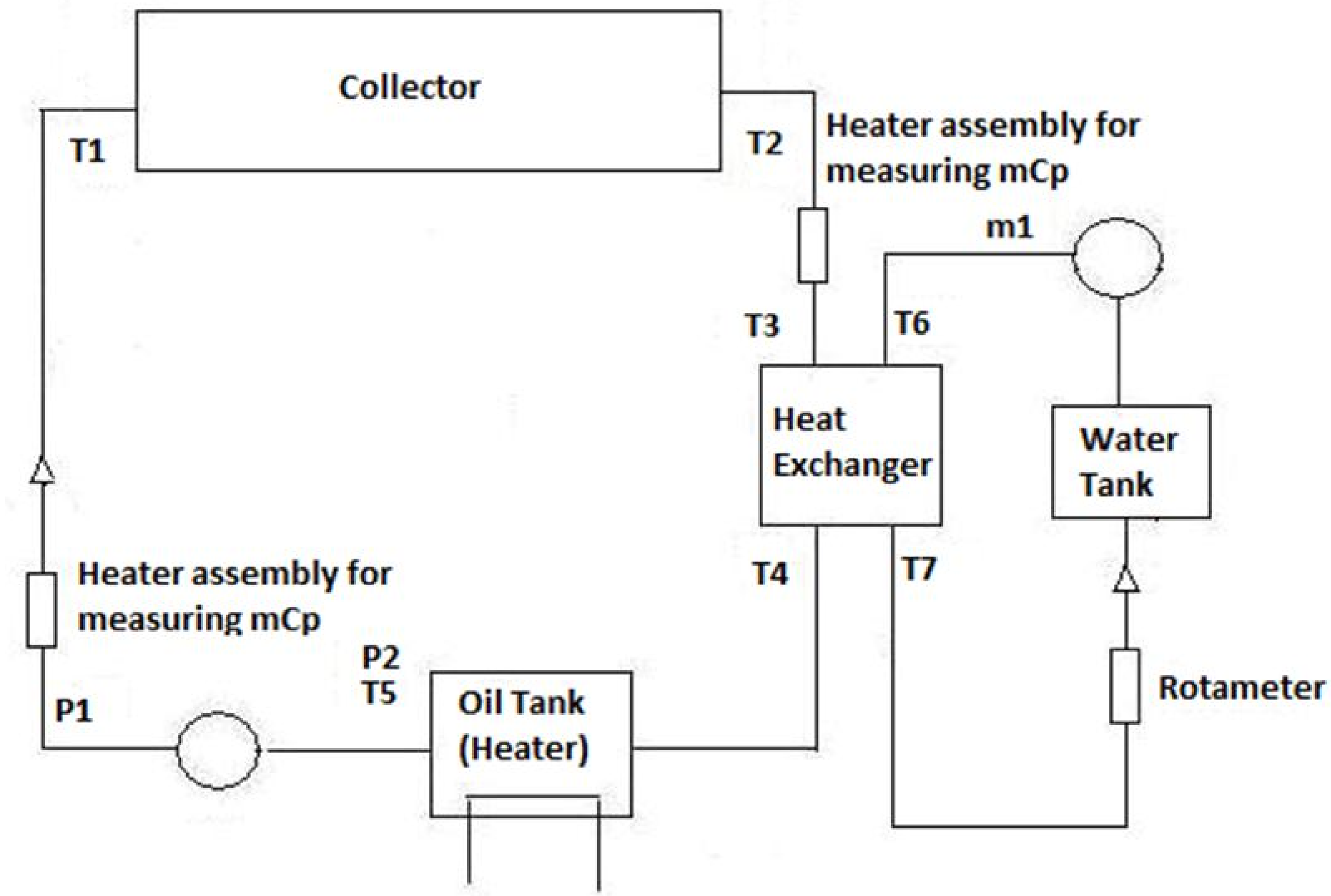
Turbine3: 20.72 MWe

56.48 MWe

Comparison of different simulators with Solar Thermal Power Plant Simulator of IIT Bombay

		System Advisor Model (SAM) [1-3]	TRNSYS [3-4]	THERMOFLEX [5]	Solar Thermal Power Plant Simulator
1	Developed By	National Renewable Energy Laboratory	University of Wisconsin	Thermoflow, Inc.	Indian Institute of Technology Bombay
2	Renewable Energy System	Generic, includes different renewable systems other than solar thermal (e.g. Photovoltaic, Geothermal Power, Small Scale Wind)	Generic, includes different renewable systems other than solar thermal (e.g. Photovoltaic, Geothermal Power, Wind)	Generic, Focus on Solar Thermal System only	Generic, Focus on Solar Thermal System only
3	Concentrating Solar Power	Includes following system only: PTC, Power Tower, Dish Stirling	Includes following system only: PTC, LFR, Power Tower	Includes following system only: PTC, LFR	Current version includes: PTC, LFR, Paraboloid Dish Next version: Power Tower
4	Power Block	Six fixed configurations	Simulation of any configuration	Simulation of any configuration	Simulation of any configuration
5	Simulation of User Defined PFDs	NO	YES	YES	YES
6	Cost Analysis	YES	NO	YES	YES (with database as well as manual entry of cost co-efficient)
7	Results reporting through tables and graphs	YES	YES	YES	Current version includes: Tabular form Next version: Graphs
8	Weather Data (Radiation, Amb. Temp. etc.)	Manual, Library	Manual, Library	Manual, Library, Model for Radiation Data	Current version includes: Manual, Library. Next version: Model for Radiation Data

Schematic of the Proposed Test Rig

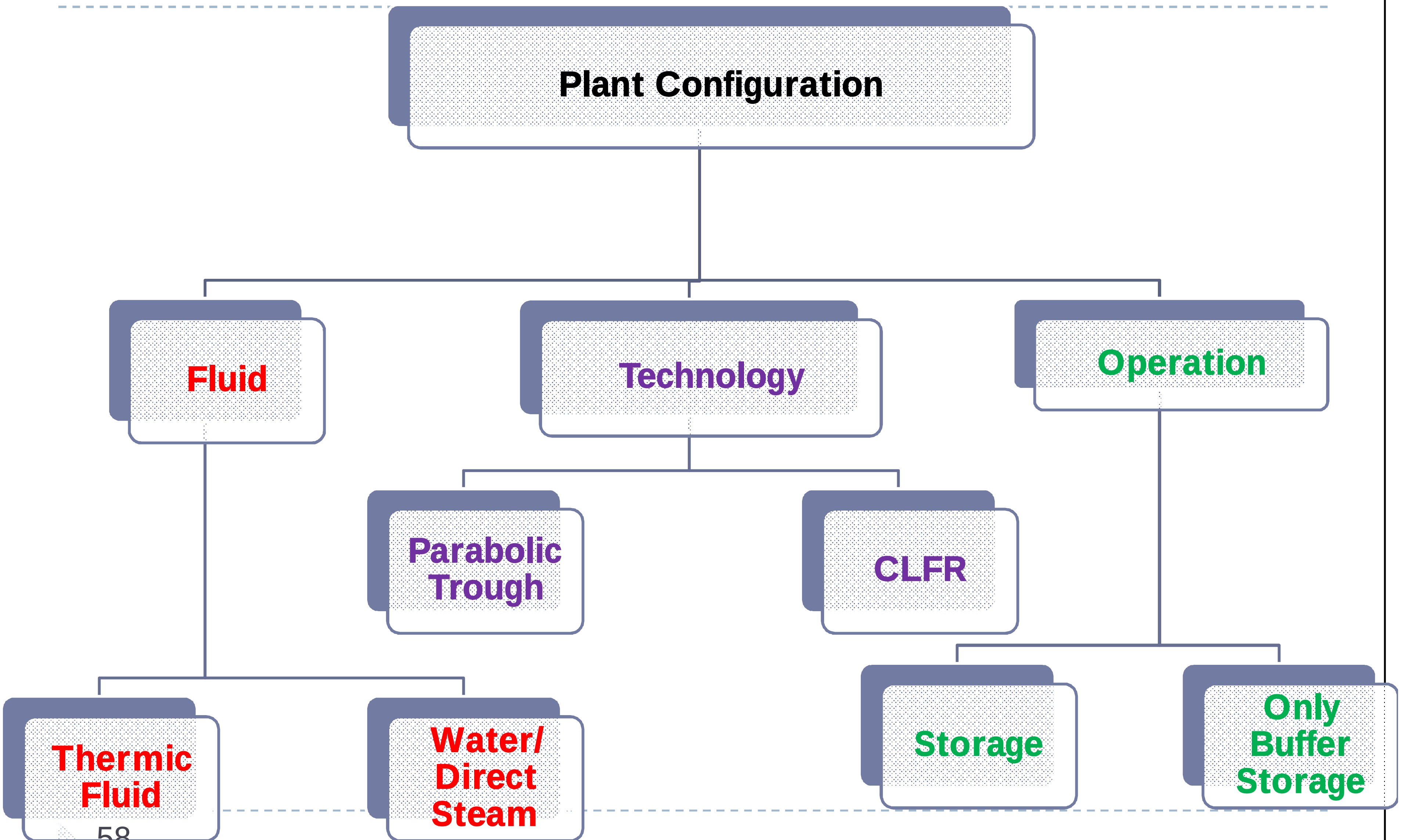


- Design and fabrication of a novel flux mapping system
- List of testing and calibration equipment needed within short term period (1 year) are being finalised

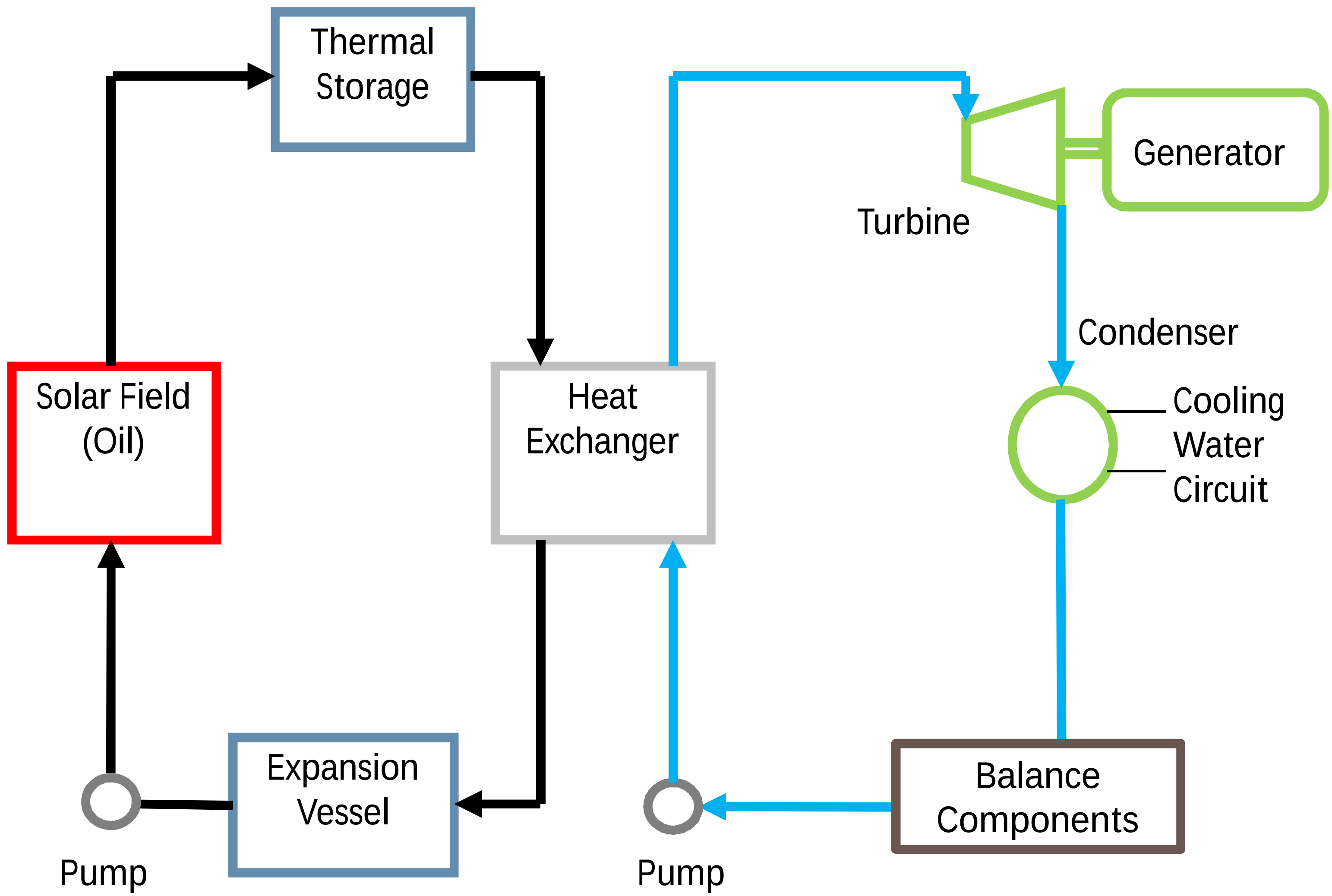
Test Facility

- Methodology for tests developed
- Test loops finalized
- Test rigs designed
- Lab testing at IITB in progress
- Procurement of test equipment and instruments done
- Test centre building plan finalized
- Provisional Patent is filed on
  - **Flux mapping system for receivers used in concentrating solar collectors**

Configuration

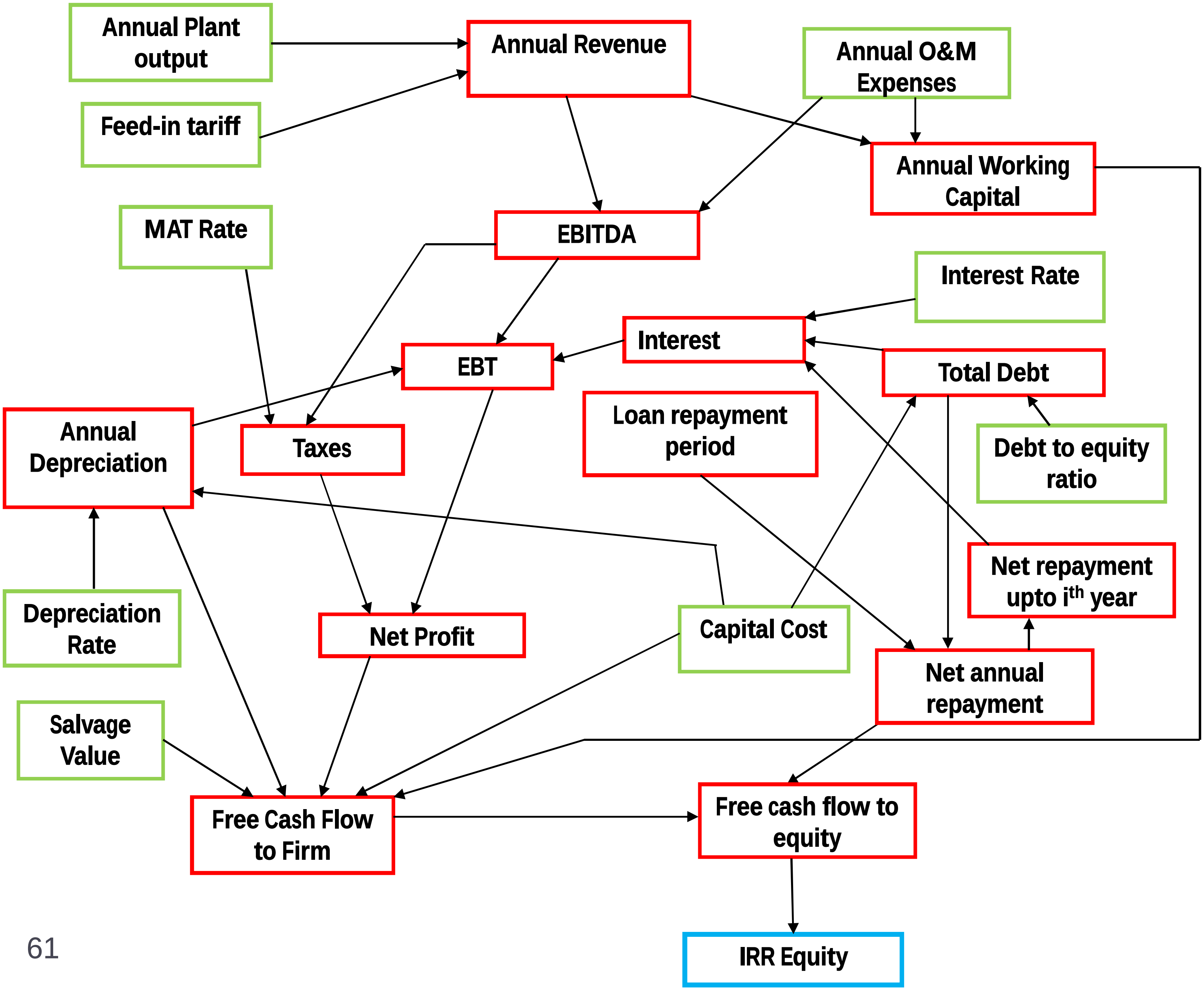


Schematic of Solar Thermal Power Plant



Assumptions – Cost Analysis

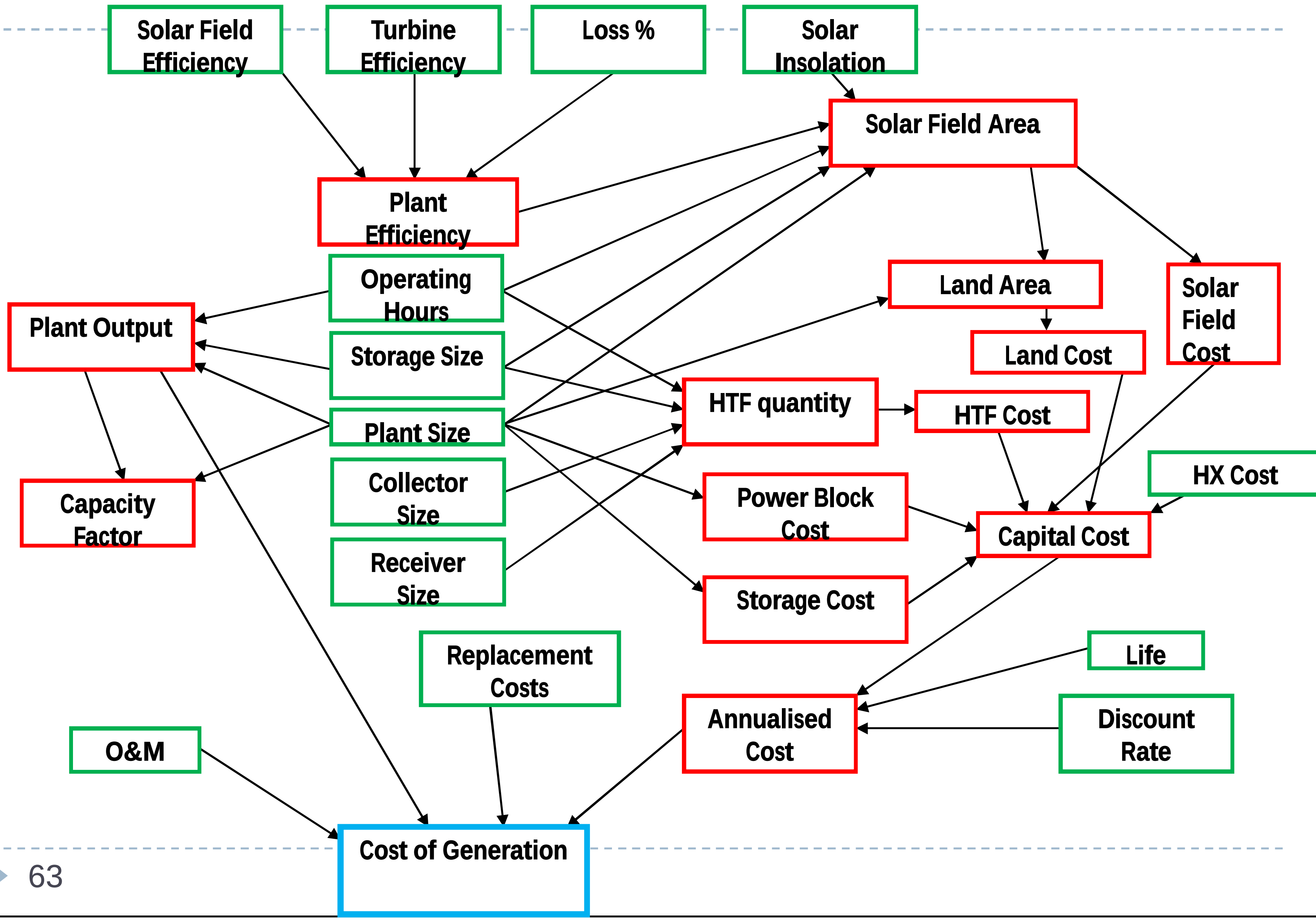
Equipment	Cost (Rs.)	Per Unit	Remarks
HX	10 Million	MWe	
PT cost	15000	m^2	
CLFR cost	10000	m^2	
HTF_{cost}	150	kg	
Mirrors	0.5	%	Annual Replacement
HTF	1	%	Annual Replacement
Receivers	2	%	Annual Replacement
O&M	3	%	Of Equipment


Annual Plant output
Feed-in tariff
Annual Revenue
Annual O&M Expenses
Annual Working Capital
MAT Rate
EBITDA
Interest Rate
Interest
EBT
Total Debt
Annual Depreciation
Taxes
Loan repayment period
Debt to equity ratio
Net repayment upto i^{th} year
Depreciation Rate
Net Profit
Capital Cost
Net annual repayment
Salvage Value
Free Cash Flow to Firm
Free cash flow to equity
IRR Equity

Base Case

- 50 MWe Solar Thermal
- 7.5 Hour Thermal Storage
- Oil Loop
- Design Solar Insolation = 650 W/m^2
- Location - New Delhi
- PT and CLFR comparison

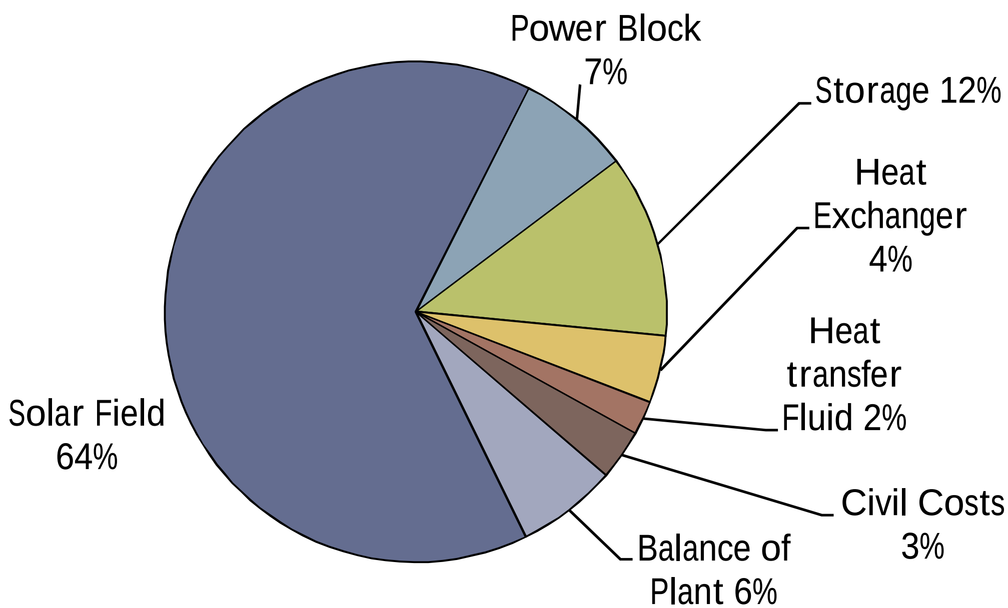
Methodology - Cost Analysis



Results – PT vs CLFR

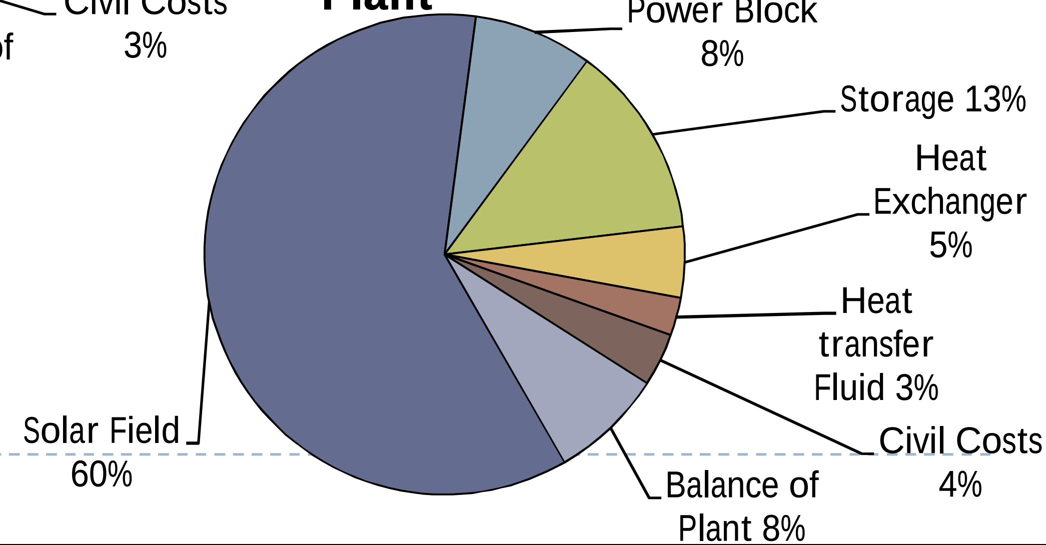
Capital Cost = Rs. 1164 Crores
Capital Cost = Rs. 233 Million / MWe
CGE = 10.54 Rs/kWh
IRR = 17%
Capacity Factor = 0.36

Cost Breakup – PT Power Plant



Capital Cost = Rs. 1045 Crores
Capital Cost = Rs. 209 Million / MWe
CGE = 9.69 Rs/kWh
IRR = 20%
Capacity Factor = 0.35

Cost Breakup – CLFR Power Plant

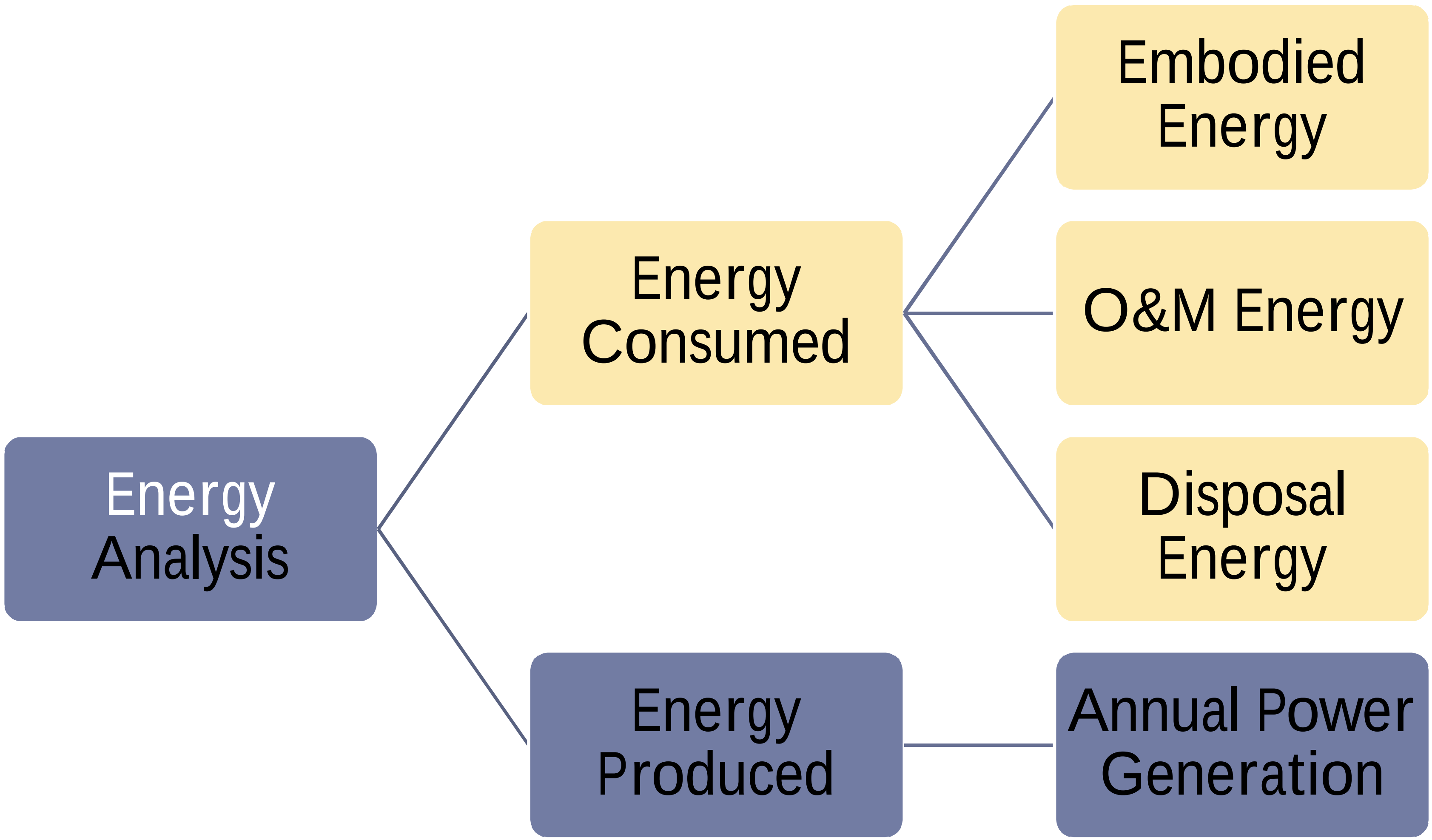


Summary of Results

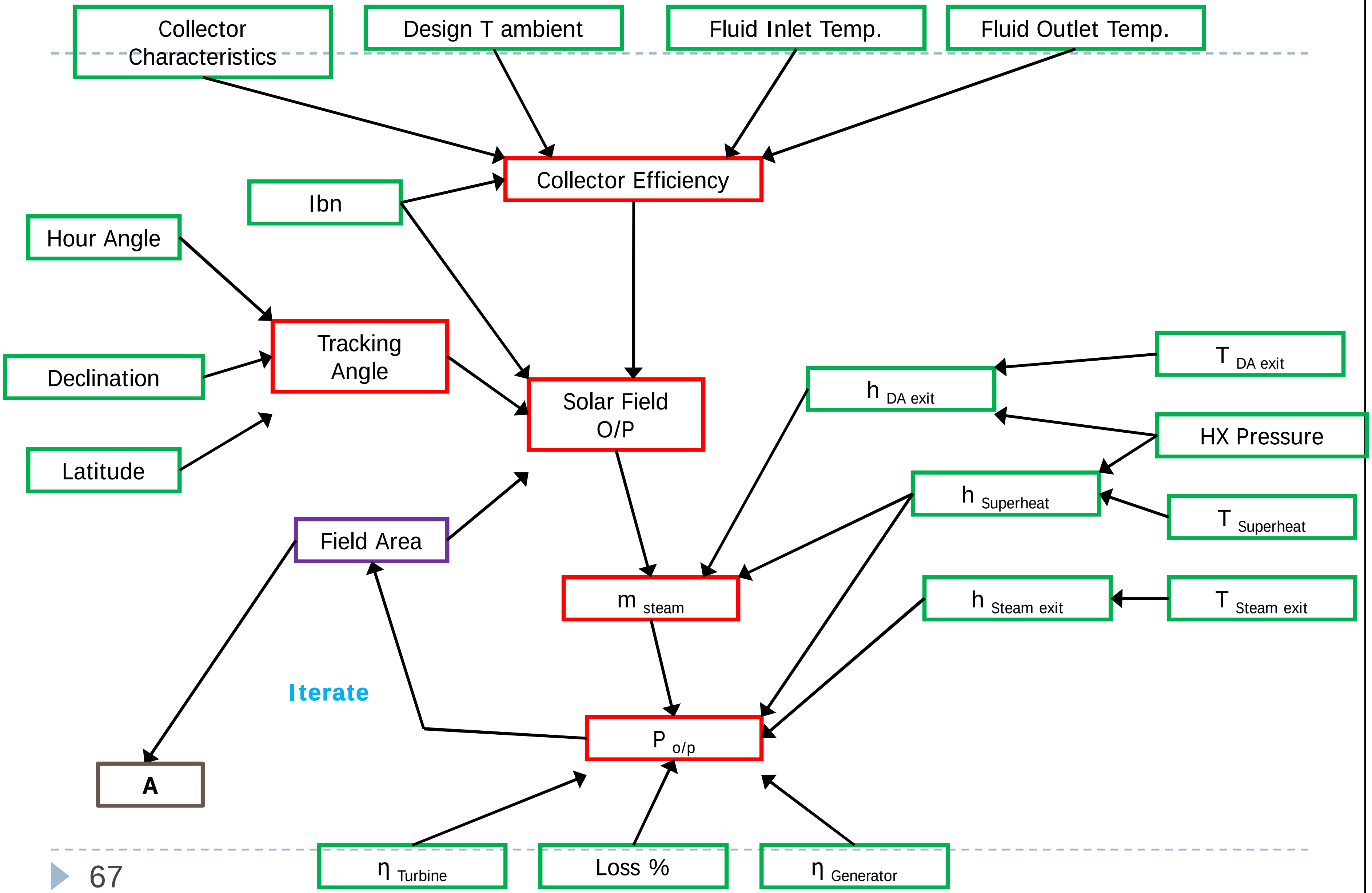
			Plant Size (MWe)								
			10			**50**			**100**		
Solar Insolation (kWh/m^2/year)	**2000**	**Rs.**	12.24	15.50	17.26	10.31	13.04	14.52	10.25	12.97	14.44
		USc	26.6	33.7	37.5	22.4	28.3	31.5	22.3	28.2	31.4
	2200	**Rs.**	11.53	14.60	16.26	9.66	12.22	13.61	9.55	12.08	13.45
		USc	25.0	31.7	35.3	21.0	26.5	29.5	20.7	26.2	29.2
	2400	**Rs.**	10.94	13.85	15.43	9.12	11.54	12.85	8.96	11.33	12.62
		USc	23.7	30.1	33.5	19.8	25.1	27.9	19.5	24.6	27.4
			6	**10**	**12**	**6**	**10**	**12**	**6**	**10**	**12**
			Discount Rate (%)								

Source: Krishnamurthy, P., Mishra, S., and Banerjee, R., Energy Policy, 2012

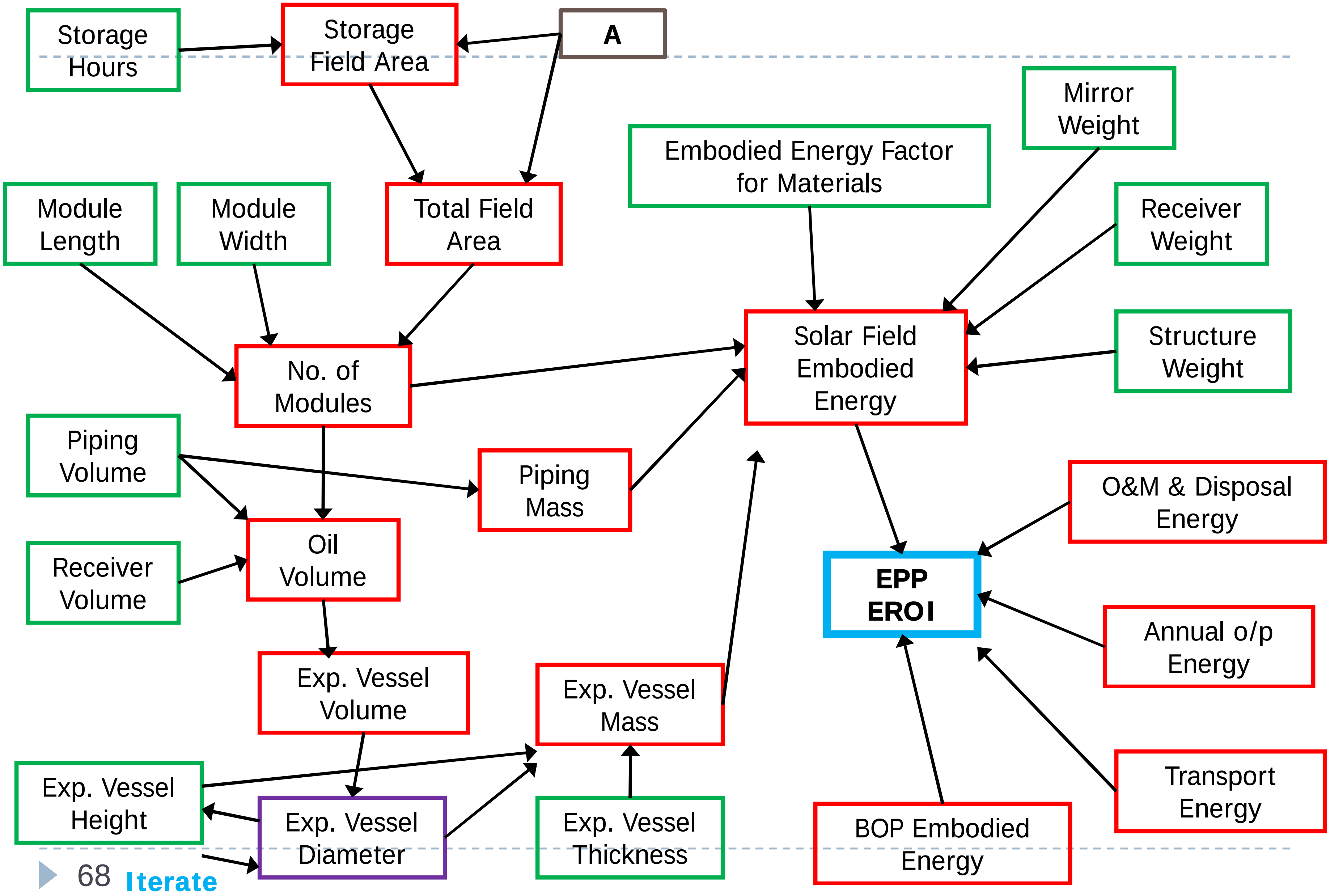
Energy Analysis



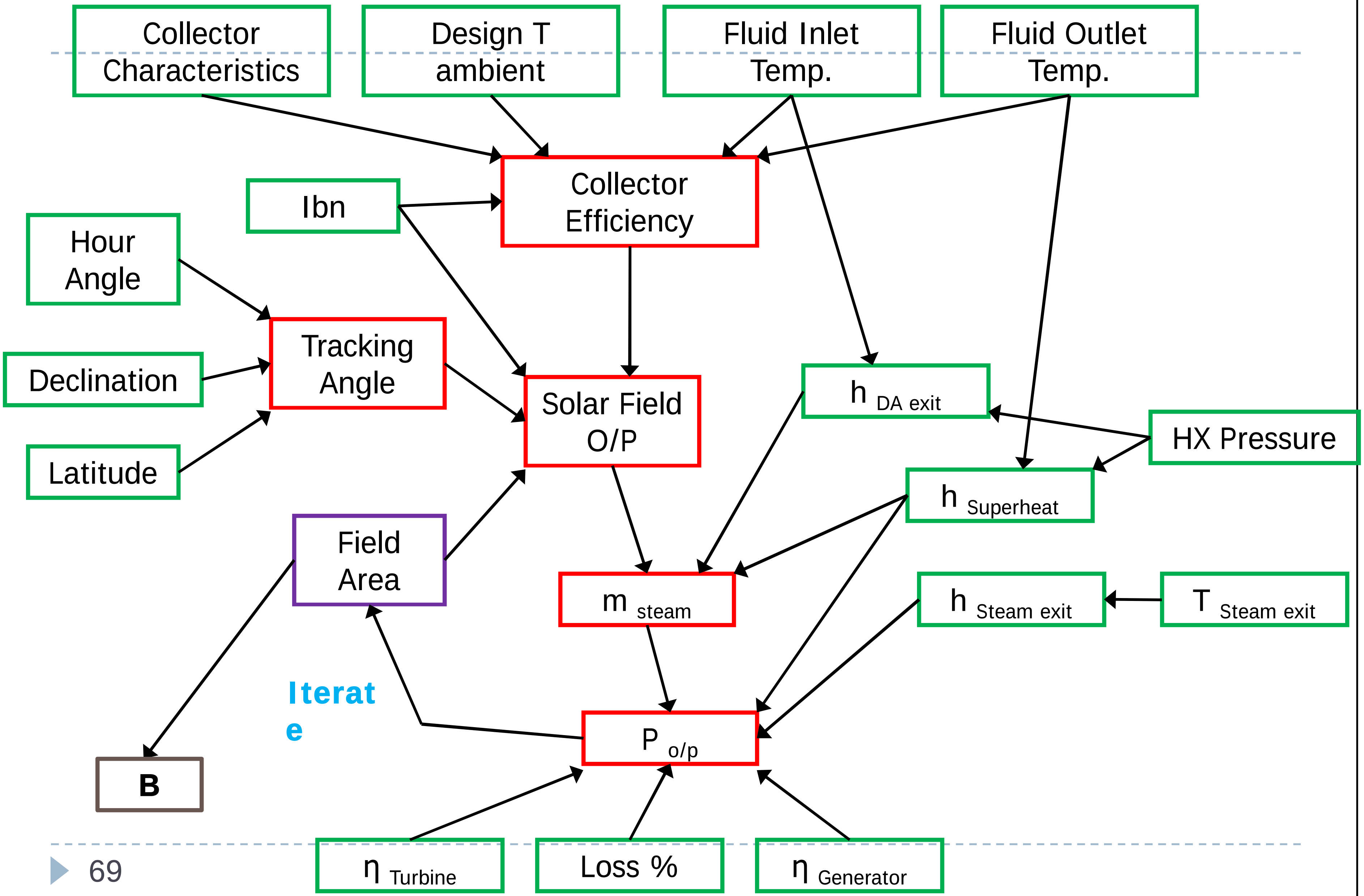
Methodology – Oil Loop



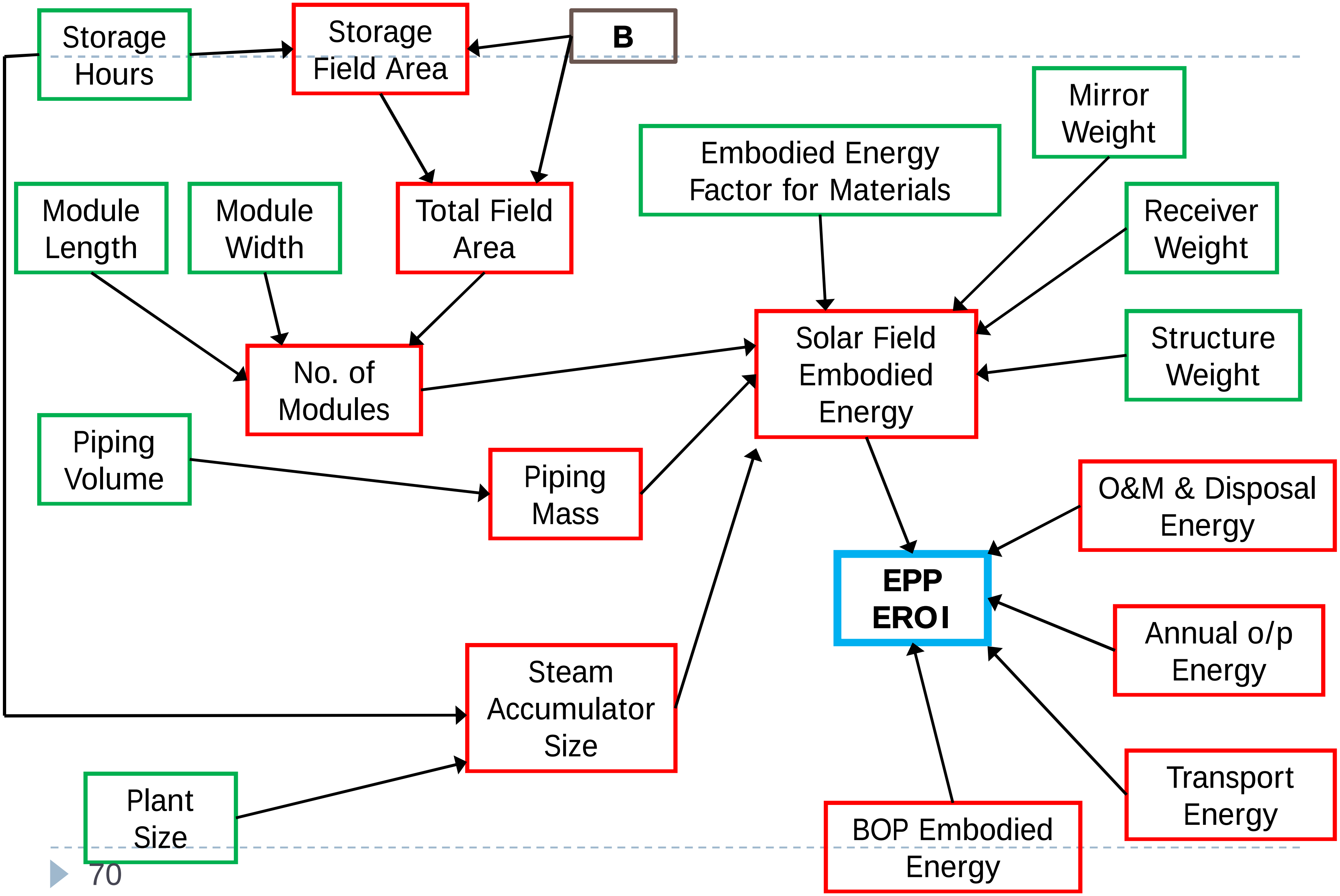
Methodology – Oil Loop



Methodology – Direct Steam



Methodology – Direct Steam



Assumptions – Energy Analysis

Factor	Value	Unit	Remarks
Plant Size	5 - 100	MWe	Range
Turbine Efficiency	50	%	Assumed Constant
Generator Efficiency	98	%	Assumed Constant
Piping and Heat loss	25	%	For Oil Loop Configuration
	20	%	For Direct Steam Configuration
Life of Plant	25	Years	
Disposal Energy	5	%	Of Total Embodied Energy
Auxiliary Consumption	10	%	Of Annual Power Generation
T_{amb}	25	^oC	
Collector Transport distance	200	km	By truck average

Material Use – Solar Collectors

Parabolic Trough – Per Module(69 m^2)

Component	Weight / Area	Unit	Material
Glass Mirrors	76.6	m2	Float Glass
HCE	8.6	kg	Borosilicate Glass
	39.4	kg	Steel
Torque Box	597	kg	Steel
End Plate	186	kg	Steel
Cantilever Arms	384	kg	Steel
HCE Supports	113	kg	Steel
Torque Transfer	32	kg	Steel

CLFR – Per MWe (@650 W/m^2)

Component	Weight / Area	Unit	Material
Steel	44000	kg	Steel
Glass	12545	m2	Float Glass
Concrete	64	m3	Concrete

BOP Material Use – Oil Loop

Material	kg/MWe
Aluminum	255
Chromium	122
Concrete	74257
Copper	454
Manganese	112
Molybdenum	42
Nickel	10
Steel	39681
Stainless Steel	612
Vanadium	4

BOP Material Use – Direct Steam

Component	**Material**	**MJ/MWe**
Foundation	Concrete	400000
	Steel	700000
TG		649333
Boiler		2246667
Cooling Tower		151333
De-Aerator		576000
Steam Seal Heater		138667
Condenser		126667
Transformer	Silica	12240000
	Steel	252000
	Copper	134400

Cost Analysis

- Solar Thermal – Sustainable from energy input
- EPP = 3 to 5 years
- EROI = 4 to 7
- Effect of variation in parameters
- Cost effectiveness of technology
- Material variation
- Framework for sustainability analysis
- Comparison of Technologies

Summing up

- PV – growth, diffusion – need to enhance roof top systems
- Solar Thermal – Test facility – MW scale – enable future cost effective plants
- Limited experience in power plant and solar field,Sub-critical base of researchers
- No evidence of cost reduction
- Need for public domain performance data
- Most collaborations – ‘turnkey plants’ –no focus on indigenisation
- CSP – significant potential for cost reduction

Acknowledgment


Suneet Singh
Faculty


S. B. Kedare
Faculty


J. K. Nayak
Faculty


Santanu B.
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Thank you