Combining CCS with renewable energy

Metrics of integrating CSP plants with fossil fueled CCS

M.R.Haines, IEAGHG

Incentives

- CCS is an interim solution limited in duration by availability of fossil fuels and underground storage space
- CCS uses more fuel and hence increases dependence on fossil fuel resources
- CCS investments are seen as competing with those in renewable energy.
- However renewable energy alone cannot deliver GHG emission reductions in time.

Advantages of integration

- Part of CCS scheme investment could be used to assist development of market for renewable energy sources
- CCS plants may be able to share a range of essential facilities with renewable energy generation
- CCS plants designs and layouts could be modified to leave a more useful legacy for sustainable renewable energy generation

Opportunities for integration

- Brainstorming ideas:-
  - Use concentrated solar thermal to provide heat for steam coal plants with CO2 capture
  - Use hydrogen generated in a CCS plant as

    a) back up fuel for concentrated solar thermal power generation

    b) Fuel for CAES expansion turbine
  - Provide common hydrogen storage for peak smoothing for use by pre-combustion capture and renewable power generators
  - Co-firing of biomass
  - Regeneration of solid CO2 sorbents

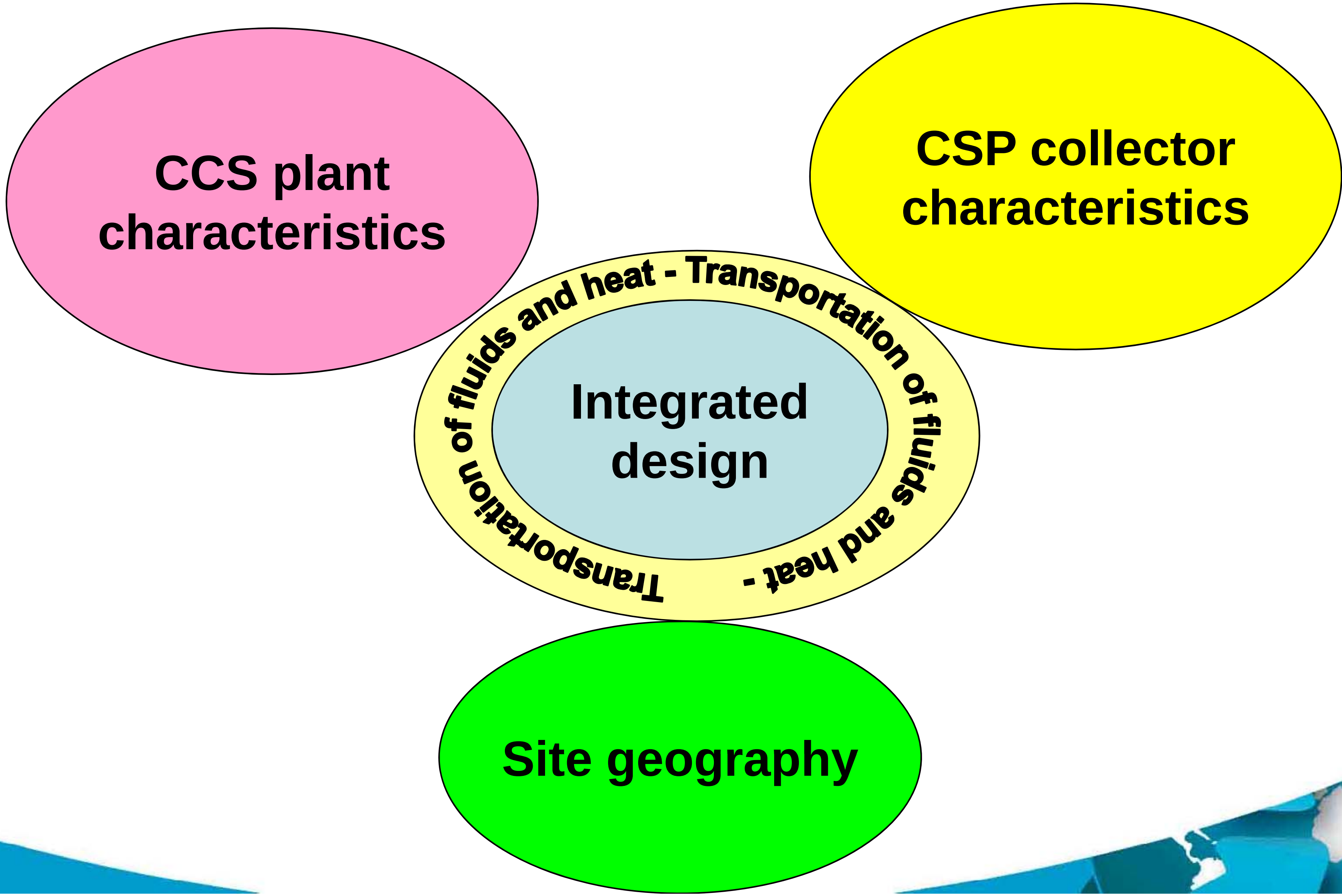
Focus of this presentation

- CSP combined with post combustion CCS

CSP and post-combustion CCS

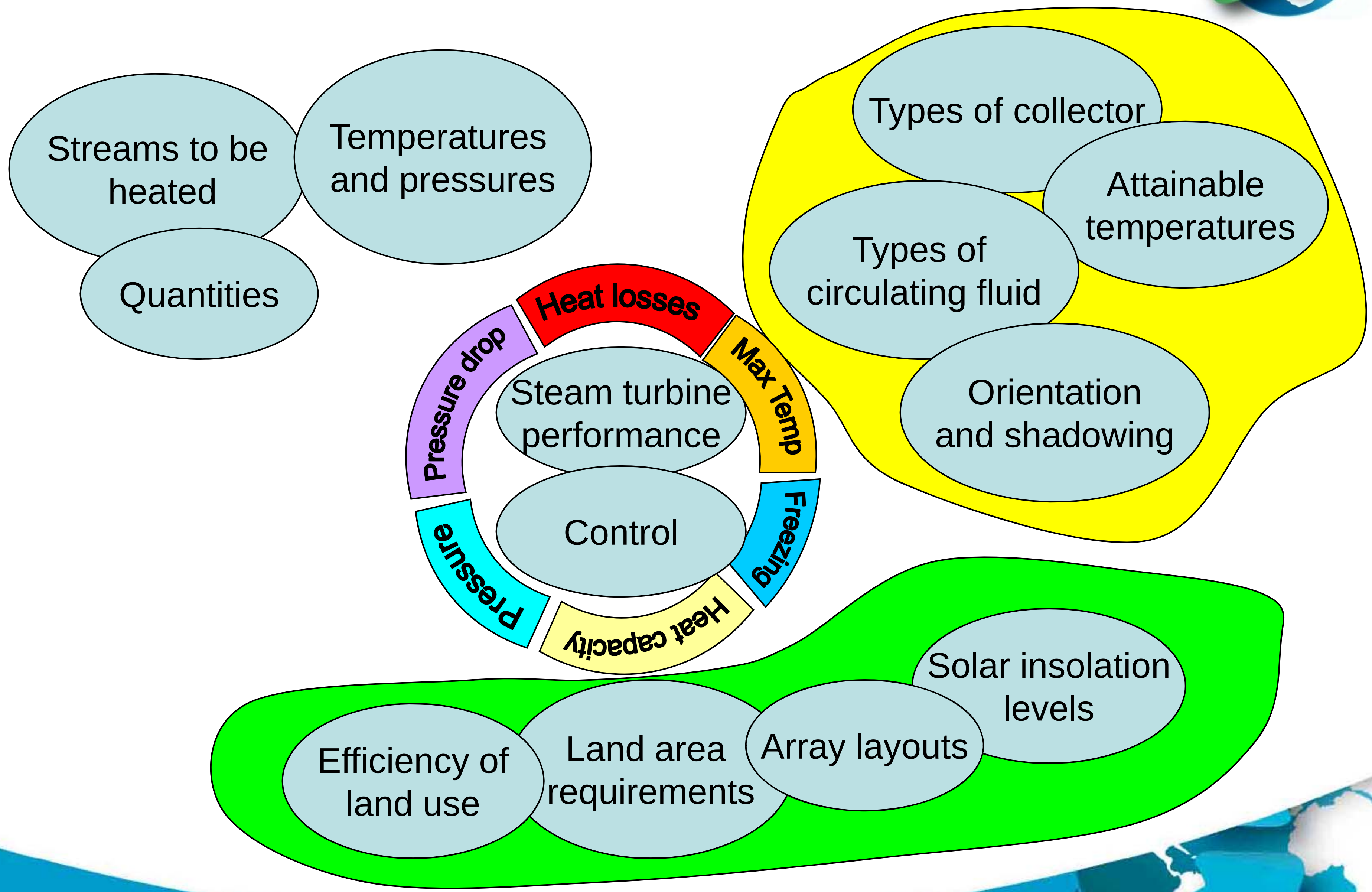
- Analysis steps
  - Thermal energy requirements of CCS plants
  - Identification of streams for heating
  - Area available and required for solar thermal arrays
  - Comparison of renewable alternatives
  - Types of array and capabilities
  - Heat transport and energy storage considerations
  - Matching array type, transport medium and heat requirements
  - Effects on overall efficiency
  - Spatial layout of CCS plant and arrays

Analysis



CCS plant characteristics
CSP collector characteristics
Integrated design
Transportation of fluids and heat - Transportation of fluids and heat -
Site geography

Matching Processes



Streams to be heated

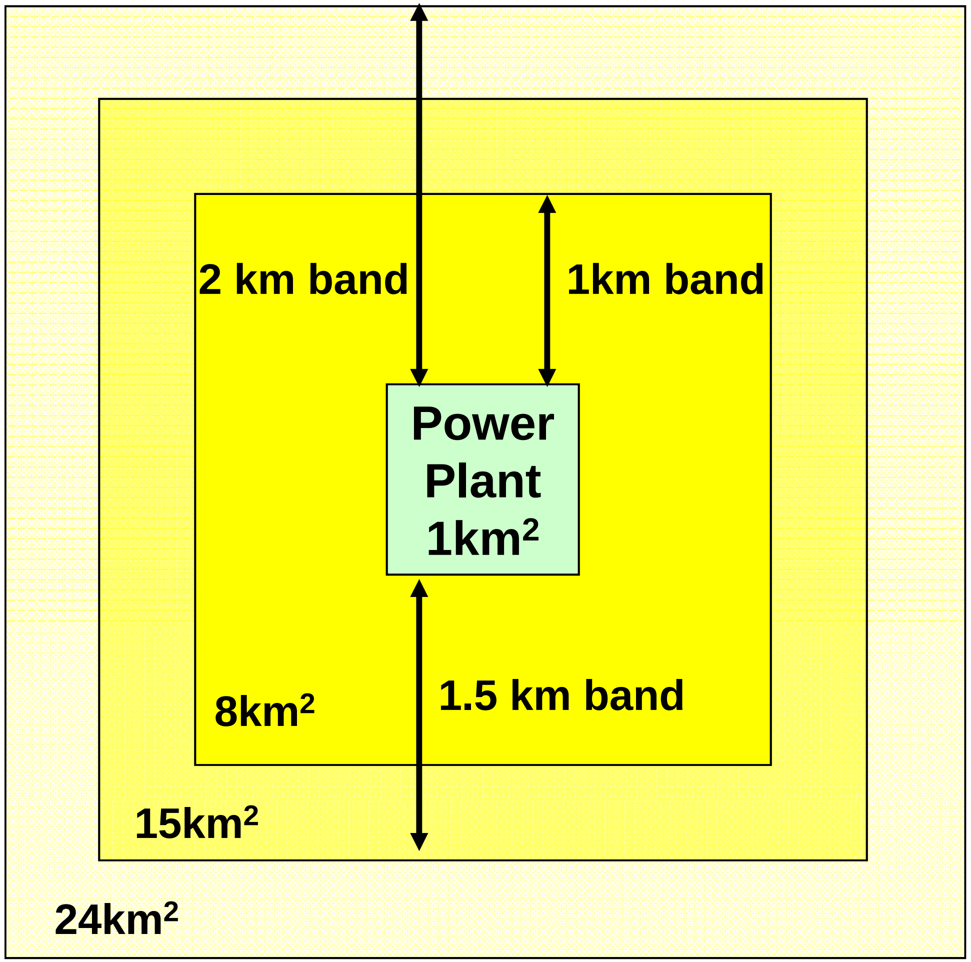
Stream	Temp trajectory Deg C	Fluid	Heat source displaced	Thermal duty % of total	Power conversion efficiency
Preheated BFW to main boiler	**250-600**	Water → supercritical steam	FG in radiant and convection	~80%	~45%
Steam to superheater	**450-600**	Supercritical steam	FG in convection	~10%	~45%
IP steam for reheat	**300-600**	Steam at ~40bara	FG in convection	~18-20%	~45%
LP steam for BFW heating	**35-190**	Water at ~15bara	Extracted LP steam	~15%	7-20% av 14%
IP steam for BFW heating	**190-250**	Water at ~30-250bara	Extracted IP steam	~12%	27-37% av 33%
Cold inlet air	**Amb-300**	Air at 1 atm	Cool FG ex convection	~12%	~45%
LP steam for solvent regeneration	**130-140**	LPsteam	Extracted LP steam	~25%	~20%

Solar heat collection fluids

Fluid	P & T Typical range	Max ht Cap‡	Density kg/m^3	Line size*	Key Limitations
Hot water	To 60barg To 290C	278	730	20in	Low temp
LP steam	2-5barg 120-165C	630	3.7	38in	Pressure drop
MPsteam	20-50barg 200-600C	845	12.7	22in	High pressure
HP steam	100-200barg 300-600C	815	55	16in	Very high pressure
Hot oils	5-10barg 100-370C	140	800	22in	Thermal degradation, H_2 invades vacuum
Molten salts	5-10barg >130-540C	150	1680	16in	High freezing temperature

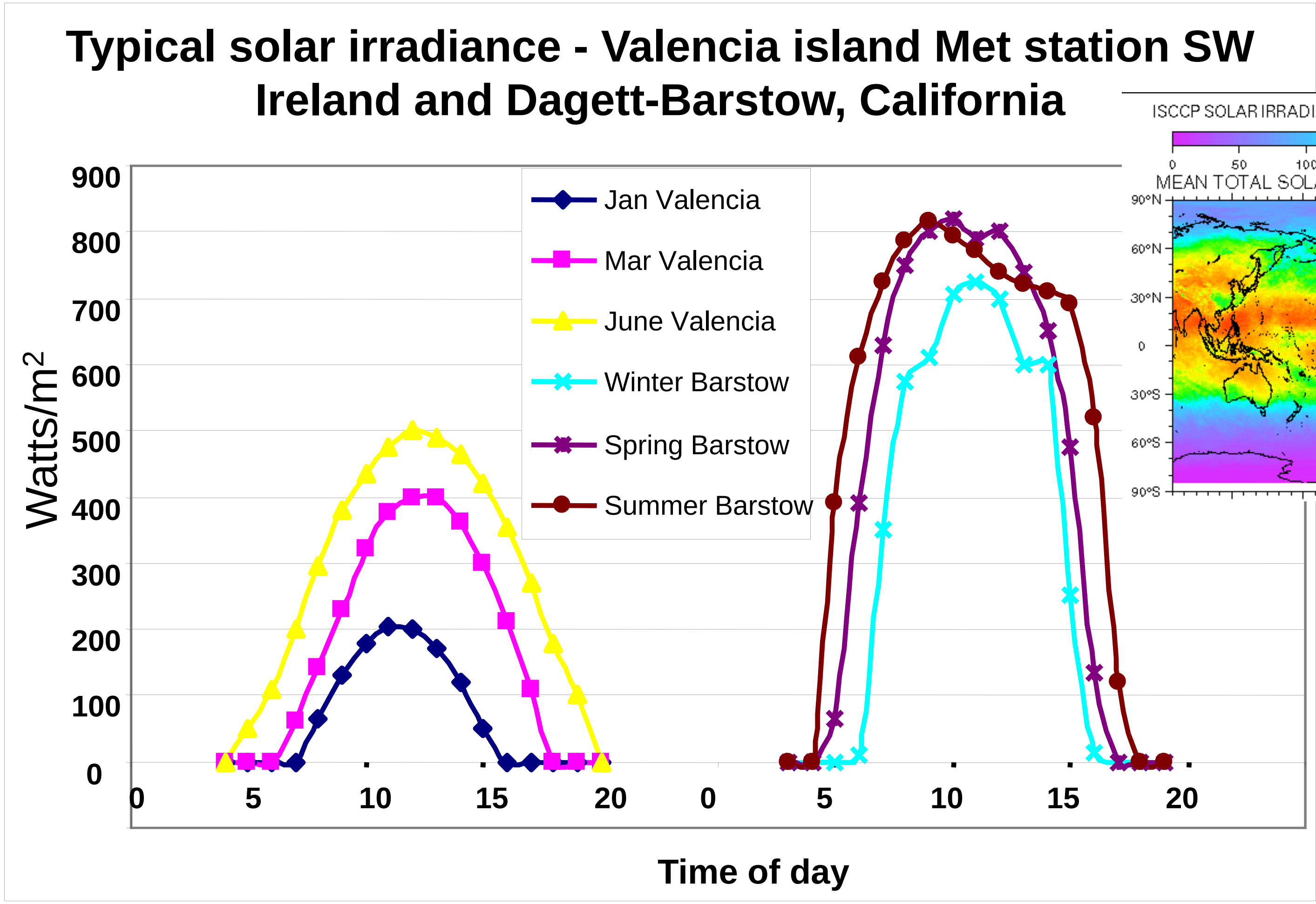
‡ Cal /gm assumes typical return temp **Approx size for 100MWe equivalent 2bar/km**

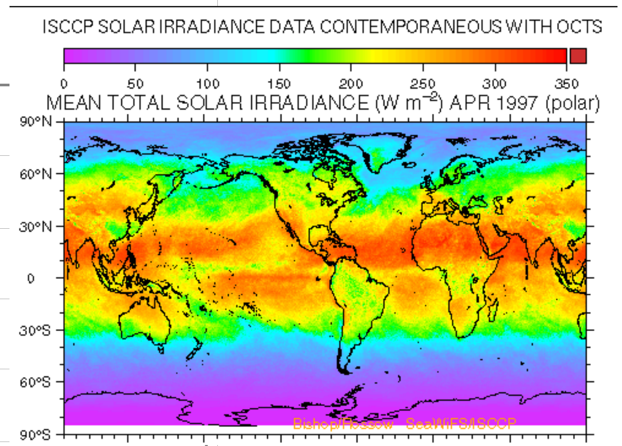
Relative areas around plant



Areas for solar array around power plant

Typical daily solar irradiance





Types of concentrated solar power array

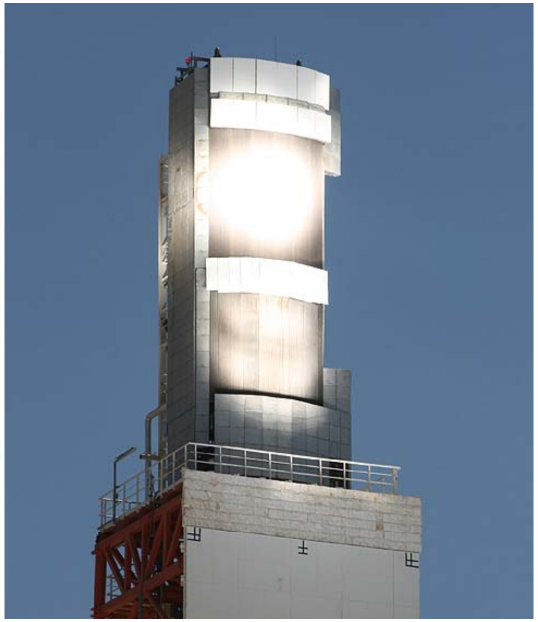
parabolic trough (PSA)

solar tower (SNL)

linear Fresnel (Solarmundo)

parabolic dish (SBP)

Ivanpah boiler



Sources (DLR,SNL, Solarmundo,SBP)

Types of solar thermal array

Type	Concentration factor	Shading effects	Other characteristics
Flat plate	None	Minimal	Low cost, no tracking needed
Linear parabolic	70-80	Moderate	Single axis tracking
Fresnel linear	25-100	Moderate	Single axis tracking
Central tower (HT)	300-1000	Major	Dual axis tracking
Parabolic dish (HT)	1000-3000	Major	Dual axis tracking

Consider some alternatives

Method	Collection efficiency	Area useable	Conversion to AC power	Relative power
Biomass Low yield	.3%	80%	45%	2.1
Biomass high yield	.8%	80%	45%	5.5
PV high eff	15%	70%	90%	180
PV low eff	10%	70%	90%	120
CSP low temp	30%	70%	25%	100
CSP high temp	30%	30%	40%	69

Power densities

- 1GW power station ----- Occupies ~1km^2
  - Electric power density = 1000w/m^2
  - Thermal power density = 2222w/m^2
- Solar insolation (1.5km band = 15km^2)

  Design range peak insolation 500-1000w/m^2
  - Average insolation* 100-250 w/m^2
  - **Max continuous available =**

1500 - 3750MW$_{thermal}$

**** 100 Typical for UK locations, 250 typical for prime solar locations***

Power densities continued

- Useable collection area 20% - 80%
- Thermal collection efficiency 30% - 50%

HENCE Thermal collection efficiency 6% - 40%

- Power conversion efficiency 30% - 15%

HENCE Incident solar to electric power 2% - 6%

THUS Effective power density: temperate = 2 – 6 w/m^2

prime = 5 – 15 w/m^2

THUS Max renewable generation

Temperate location = 30 - 90MWe

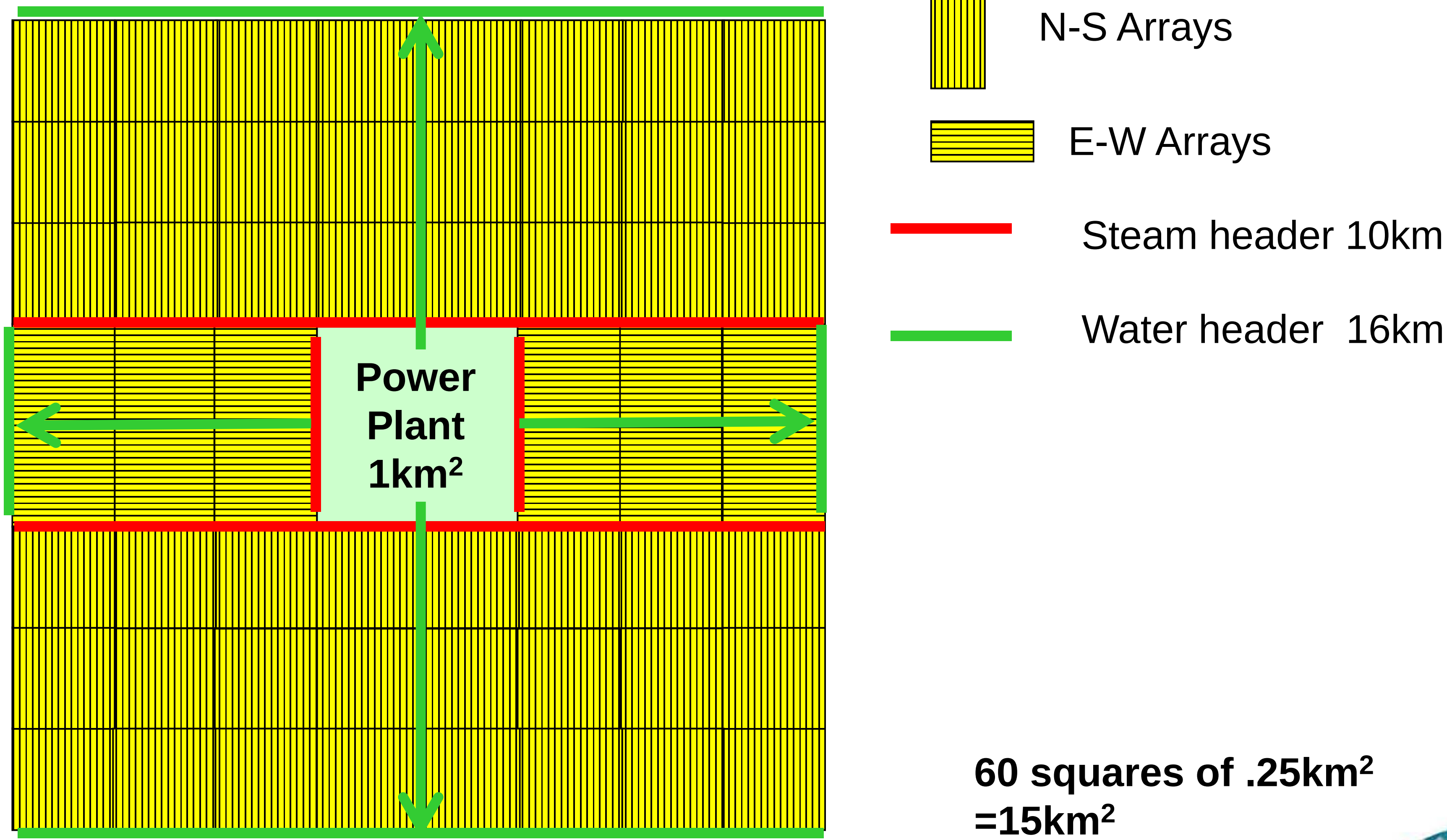
Prime location = 75 - 225MWe

Matching peak supply

Peak solar intensity	1km collection band	1.5km collection band	2km collection band
500w/m2	830 MW_{th}	1560 MW_{th}	2500 MW_{th}
1000w/m2	1660 MW_{th}	3120 MW_{th}	5000 MW_{th}

Duty to be replaced	MW thermal
LP steam for BFW heating	430MW
IP steam for BFW heating	340MW
LP steam for solvent regeneration	750MW
TOTAL	1520MW

Array orientation and headers

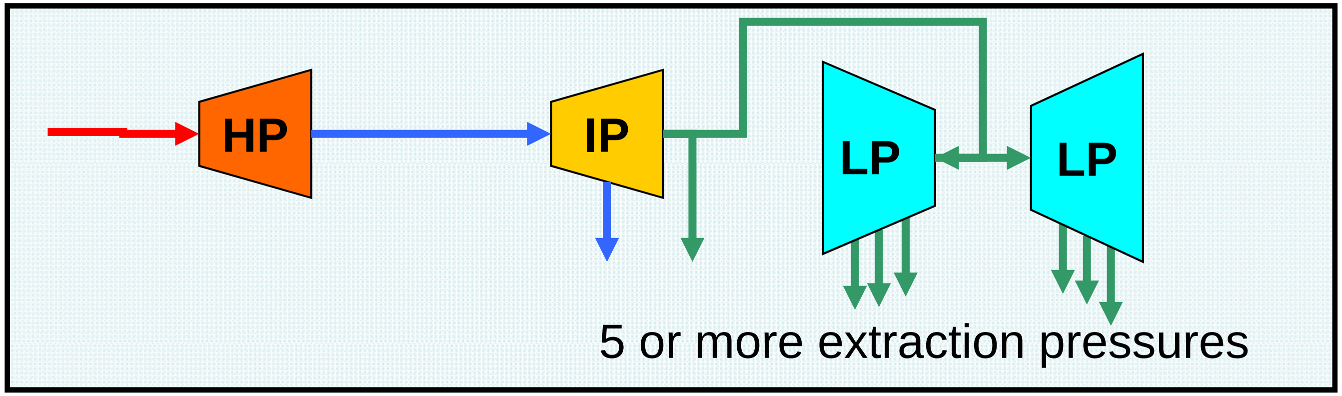


60 squares of .25km^2 =15km^2

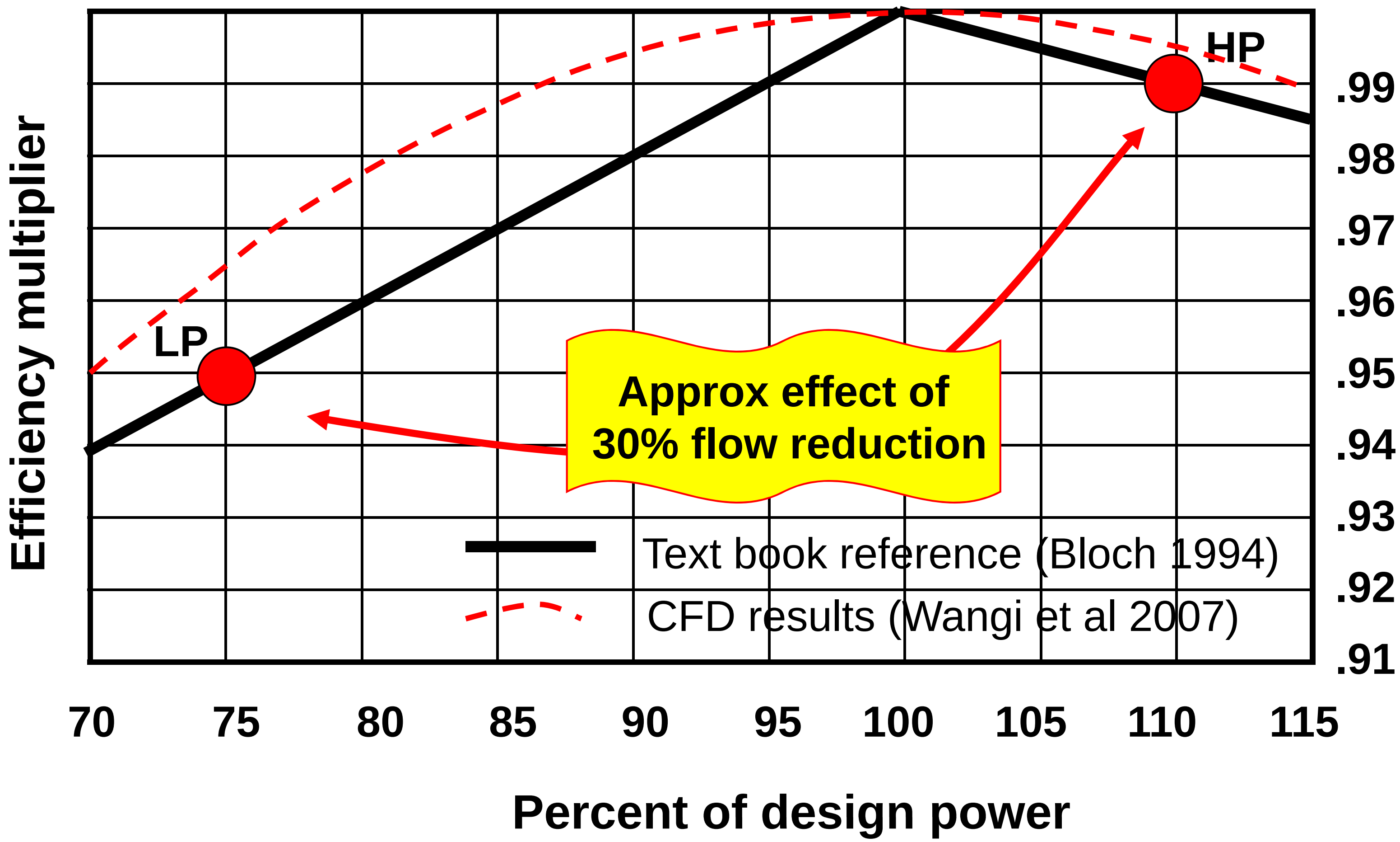
Steam turbine performance

- Steam turbines in Power plant operate at constant speed
- Maximum efficiency is with design point volume flows at every stage
- Efficiency falls off for higher or lower flows

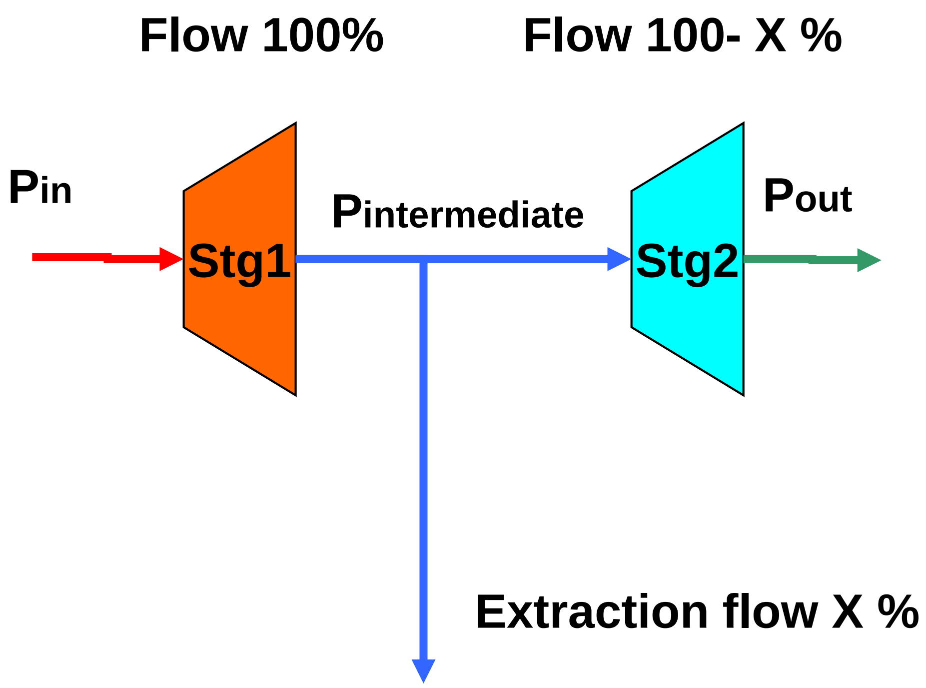
  (Steam no longer enters stages at optimum angle)
- Higher flows cause increased blade stress

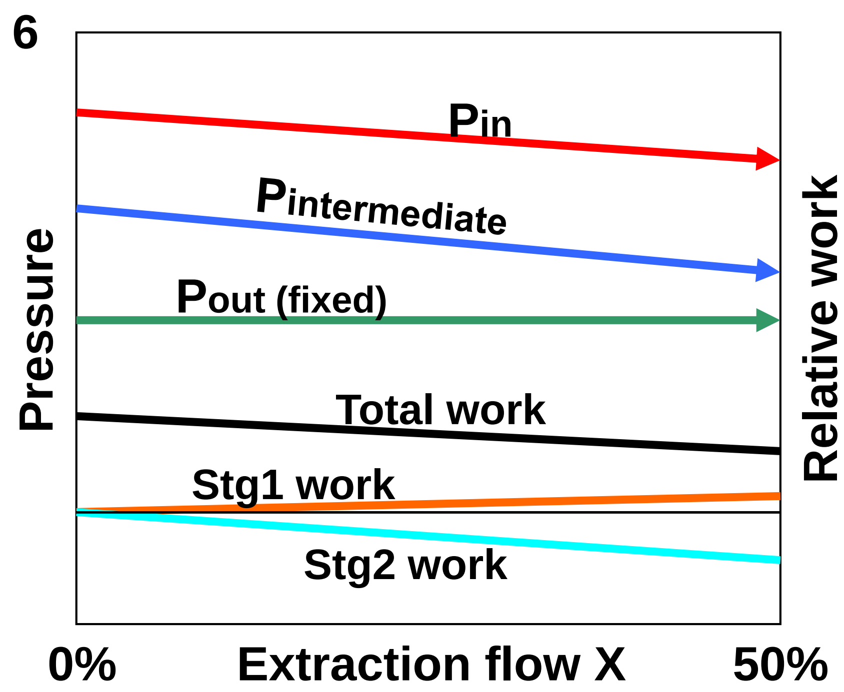


Effects of flow change on ST efficiency



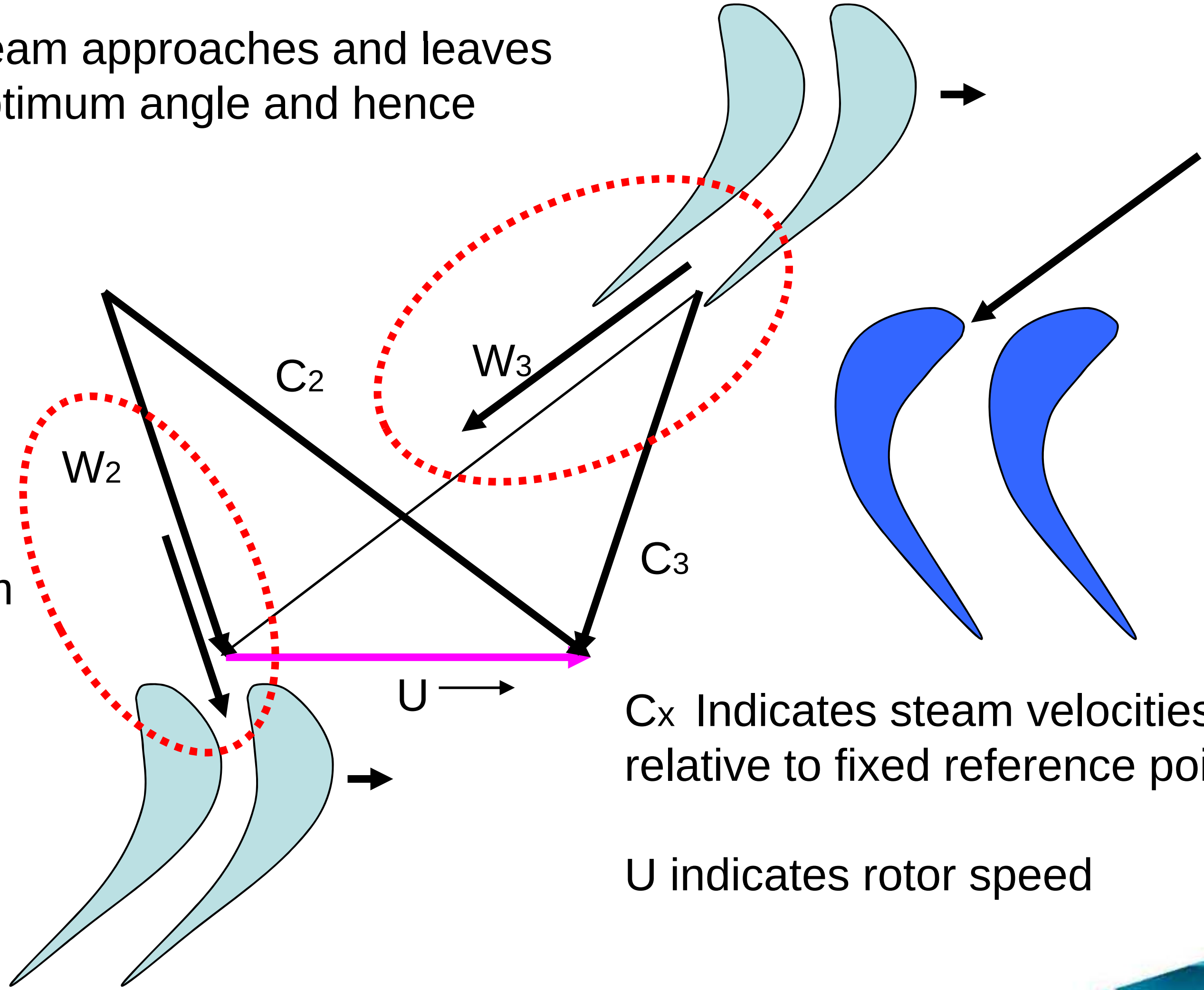
Effects of extraction flow changes





Velocity triangles

At design flow steam approaches and leaves rotor blades at optimum angle and hence efficiency is high



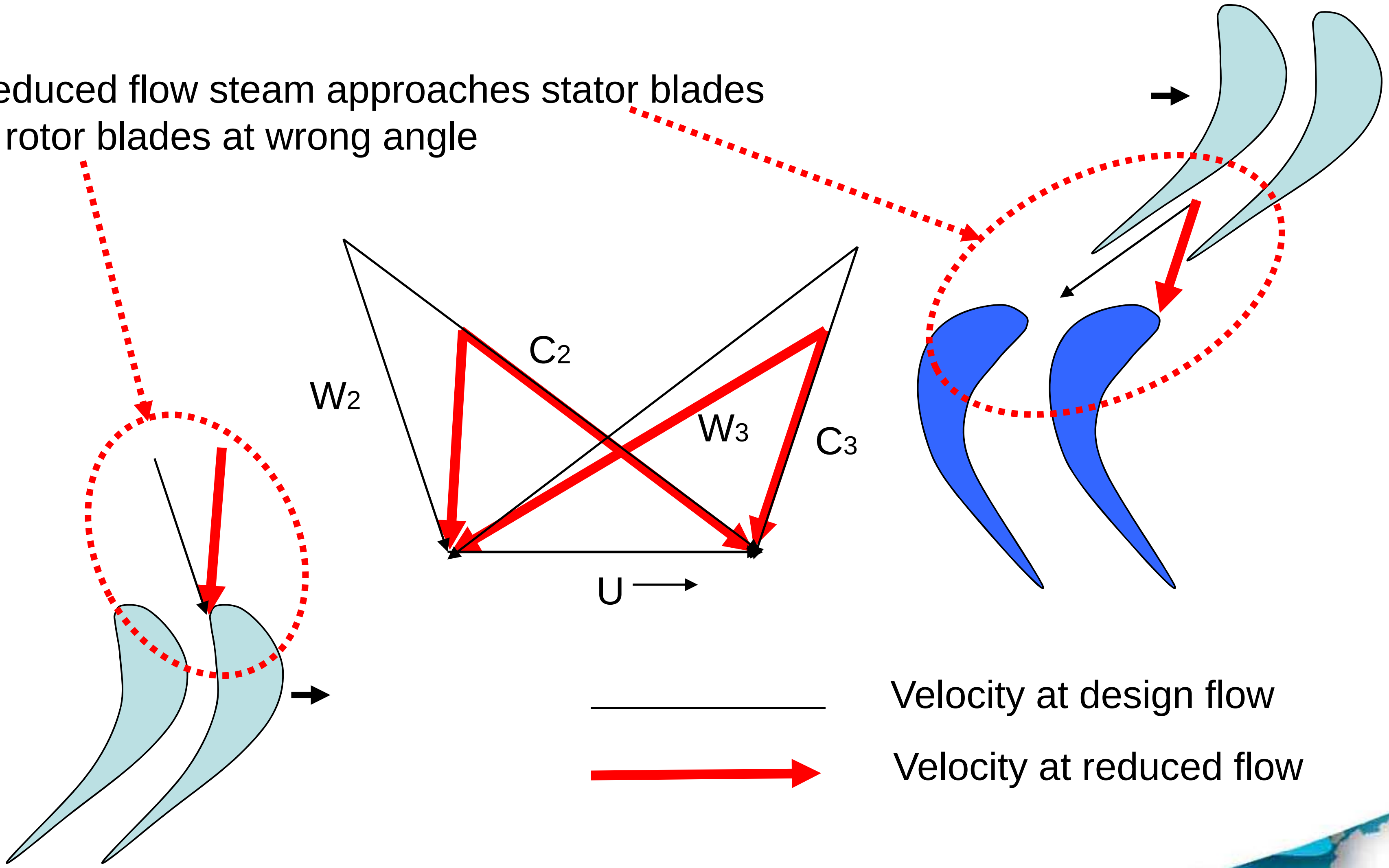
W_x Indicates steam velocities relative to rotor

C_x Indicates steam velocities relative to fixed reference point

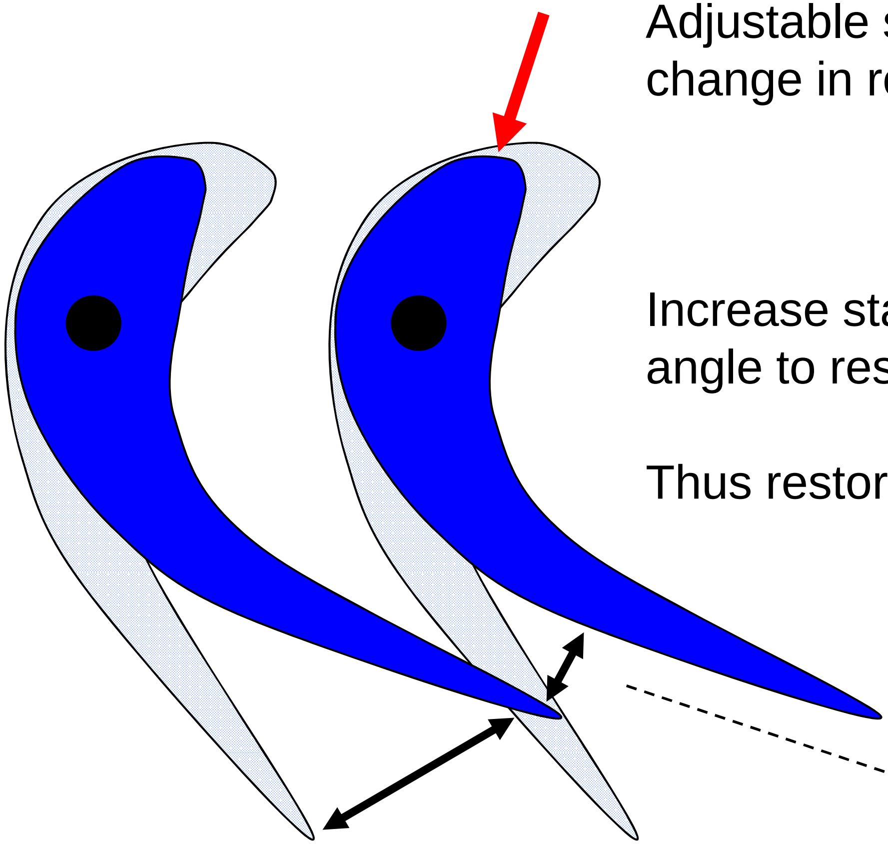
U indicates rotor speed

Velocity triangles

At reduced flow steam approaches stator blades and rotor blades at wrong angle



Adjustable stators?

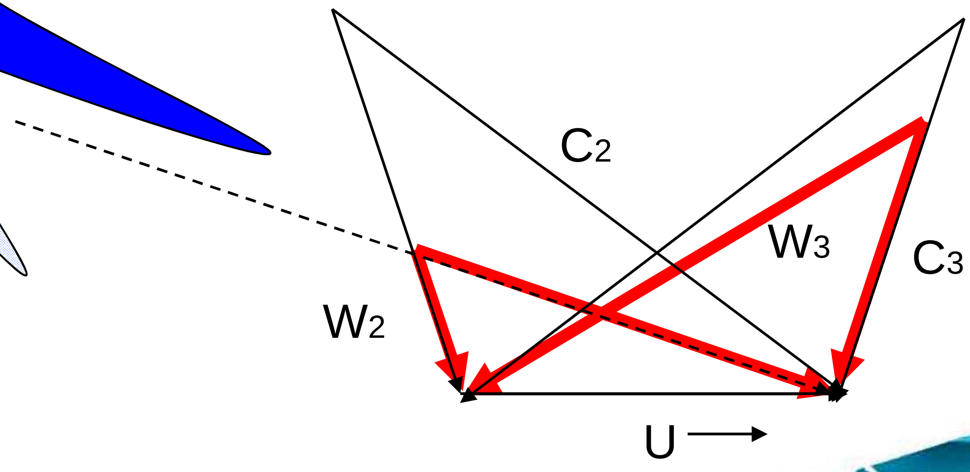


Adjustable stators could accommodate change in rotor exit direction

And

Increase stator exit velocity / alter exit angle to restore flows to optimum direction

Thus restoring lost efficiency



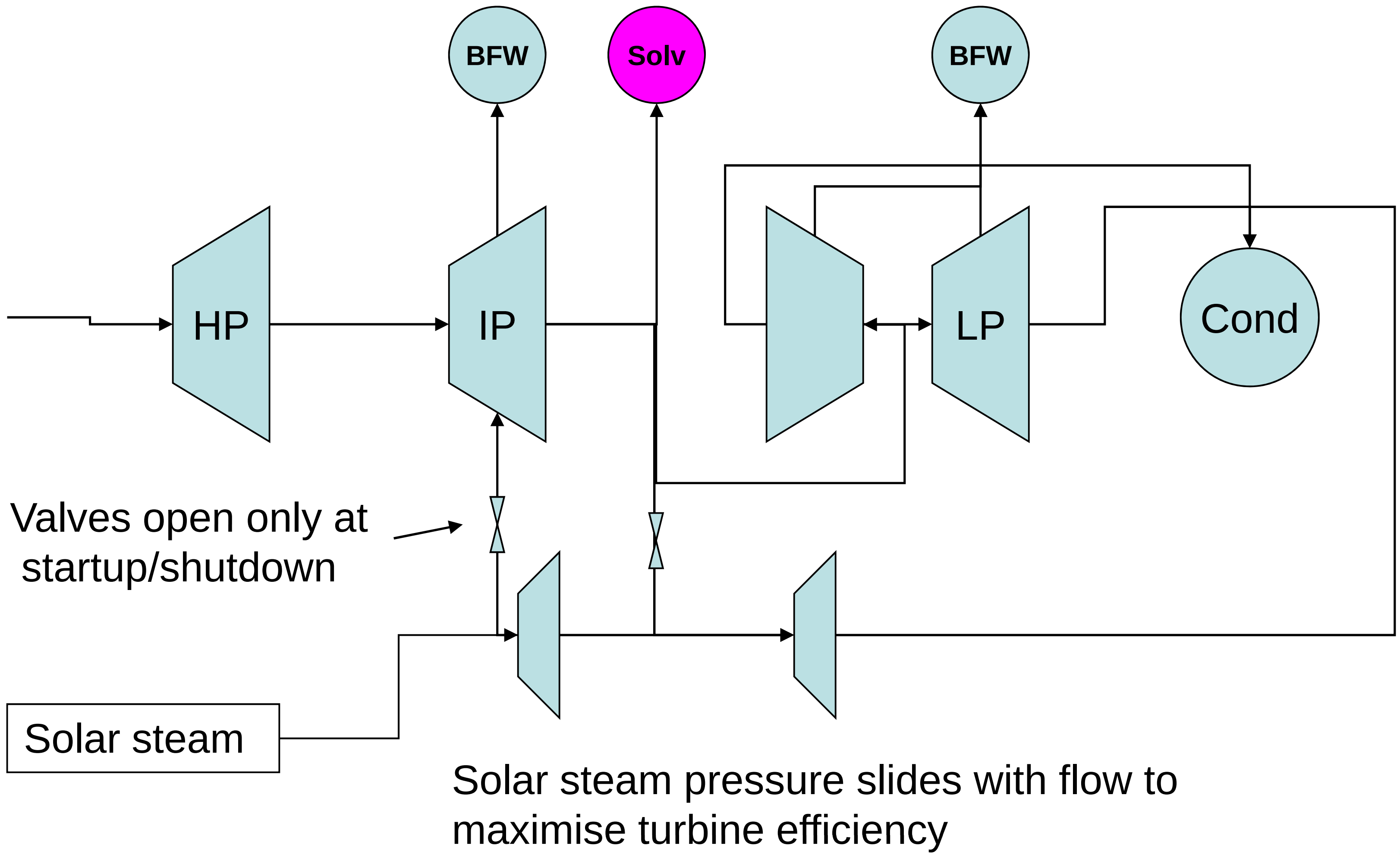
Consequences

- Some steam turbine stages would have to run most of time at low capacity

  i.e when solar energy not available

- Resultant efficiency loss would reduce advantages of efficient conversion in large machines.
- A solution is to have separate turbine for solar steam flows.
- Another future solution might be use of variable geometry stator blades

Tie in of solar steam turbines



Other benefits

- Solar steam turbine can be used to absorb extracted LP steam if CO_2 capture is temporarily stopped
- Consider splitting solar turbine into 2 machines so that swallowing capacity of one can match this.
- Splitting into two machines will improve overall efficiency outside peak solar insolation

Conclusions

- Area around a large CCS plant is sufficient to collect significant amount of solar thermal energy
- Direct steam generation using linear Fresnel arrays makes best use of the land
- Best use of the energy is through installation of a separate steam turbine system
- This would leave a permanent stand alone legacy of a small independent solar power plant

Acknowledgements

- IEA Greenhouse Gas R & D Programme
- An IEAGHG report on this work is currently being finalised

Thank you