Imperial College London

Workshop on Operating Flexibility of Power Plants with CCS, 11th – 12th November 2009

Steam turbines for operating and future-proof upgrading flexibility

Mathieu Lucquiaud, Hannah Chalmers and Jon Gibbins

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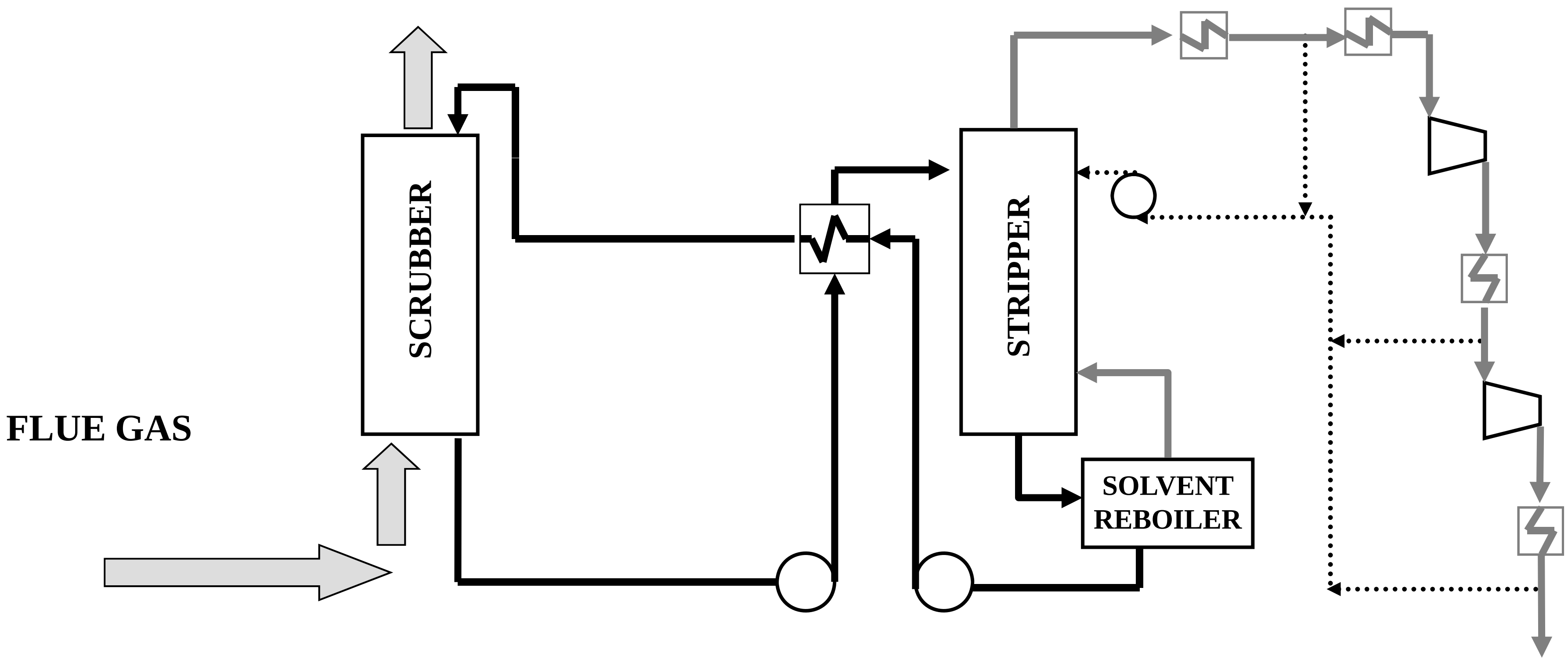
Outline

- Flexible modes of operation
  - Part-load operation
  - Absorber by-pass
  - Solvent storage and delayed regeneration

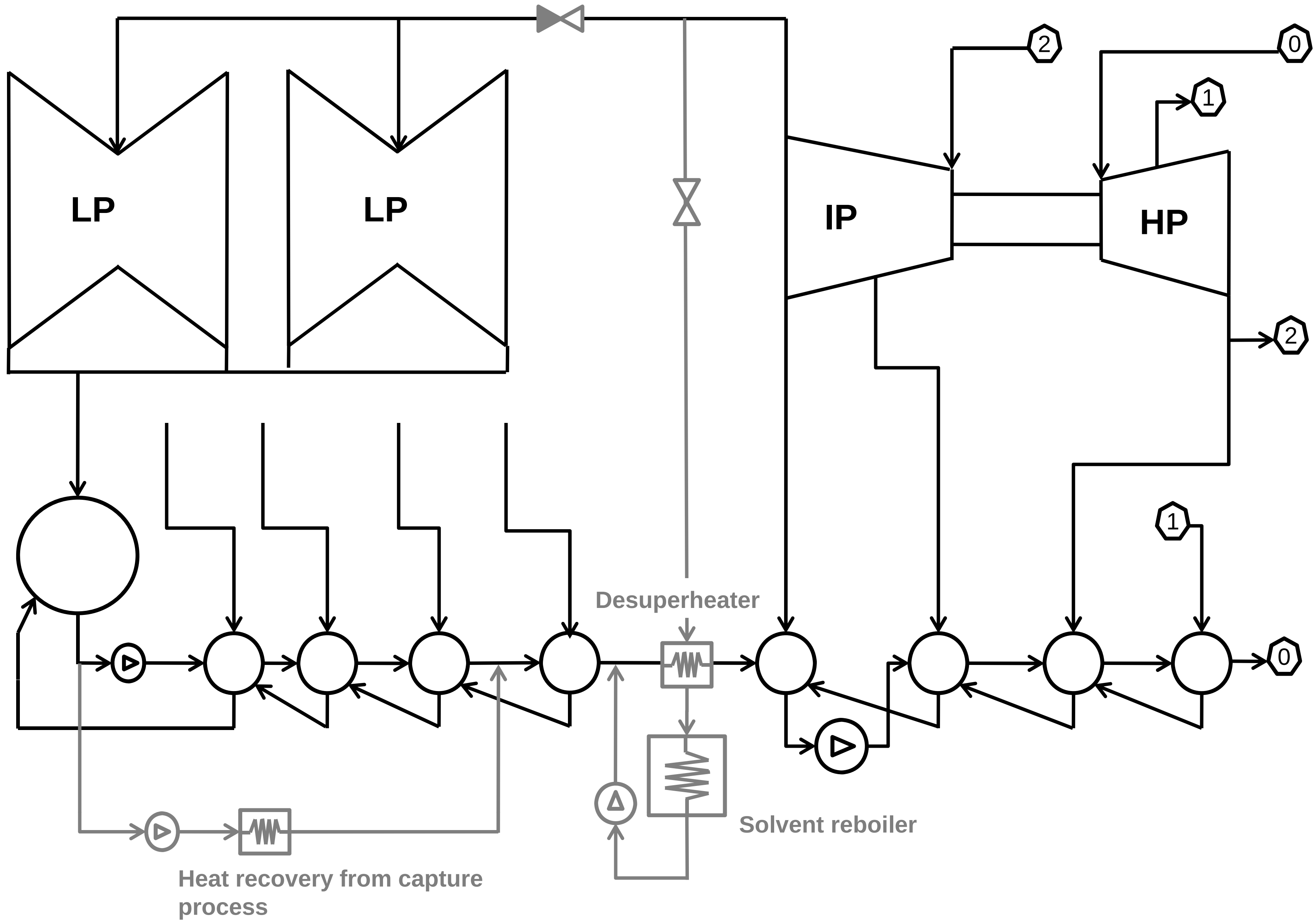
- Future-proof upgrading flexibility
  - Possible solvent improvements
  - Implications for steam cycle design

Part-load operation of capture unit



Change in flue gas flow-rate - Optimal Absorber L/G ratio?
Change in solvent flow-rate - Optimal Stripper L/G ratio?
Temperature of regeneration – Compressor operation
CO_2 output drops - Compressor operation
Temperature pinch in solvent reboiler

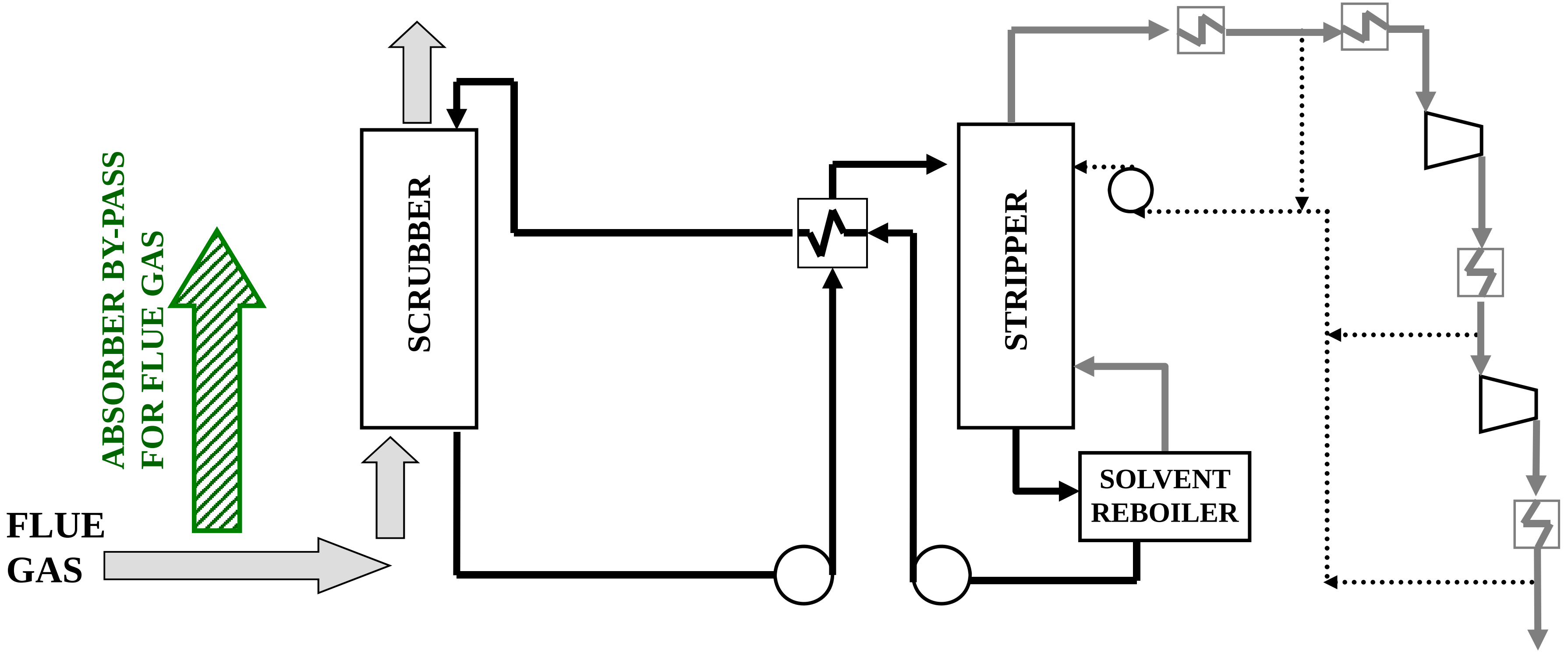
Part-load operation of power cycle



Part-load operation of power cycle

- The temperature pinch in solvent reboiler is reduced. Conduction dominates heat transfer.
- Pressure drop across steam pipe to reboiler reduces with steam flow
- The delivery pressure has to be in line with turbine part-load operation constraints

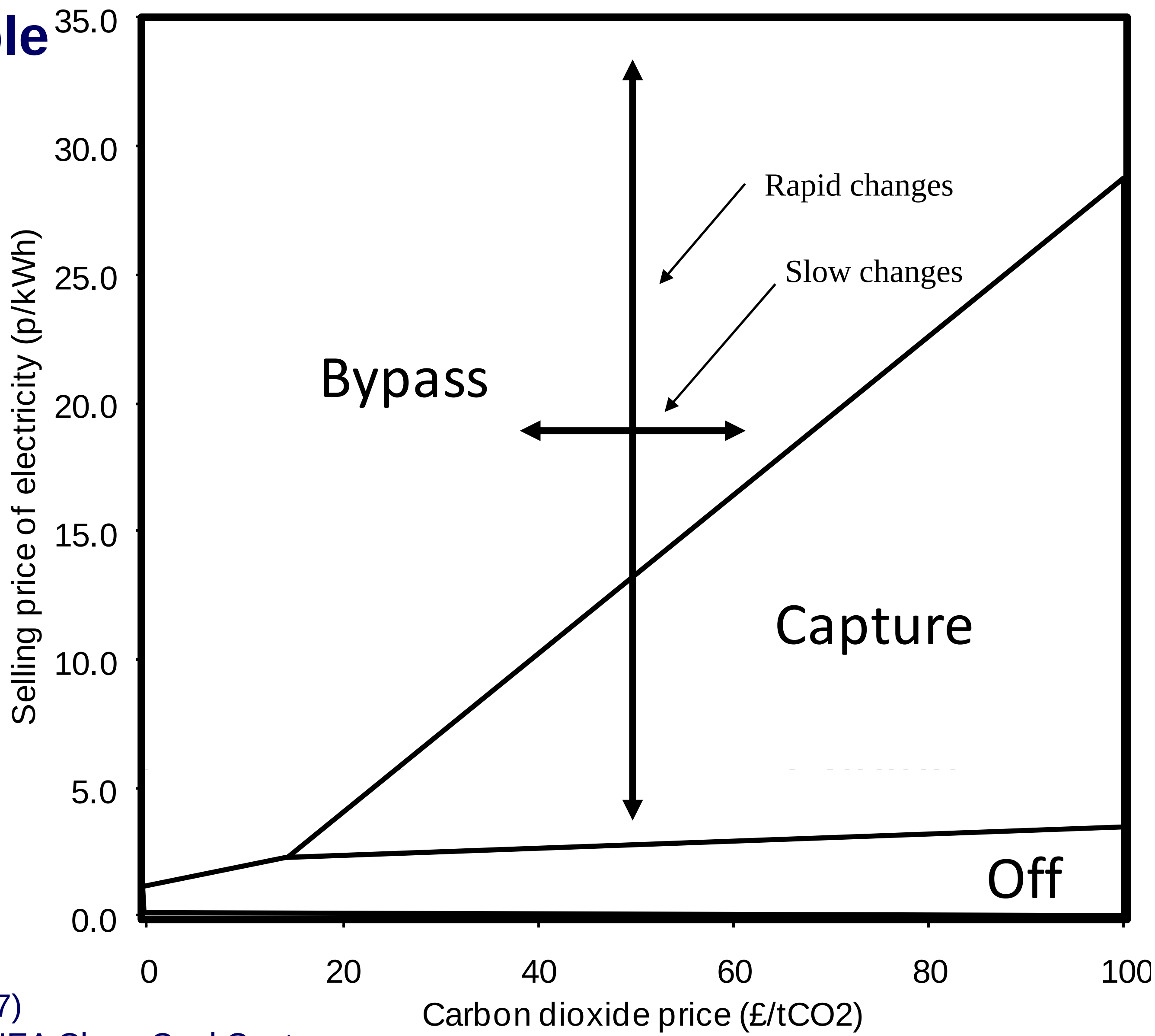
Voluntary by-pass of absorber



Operational Flexibility

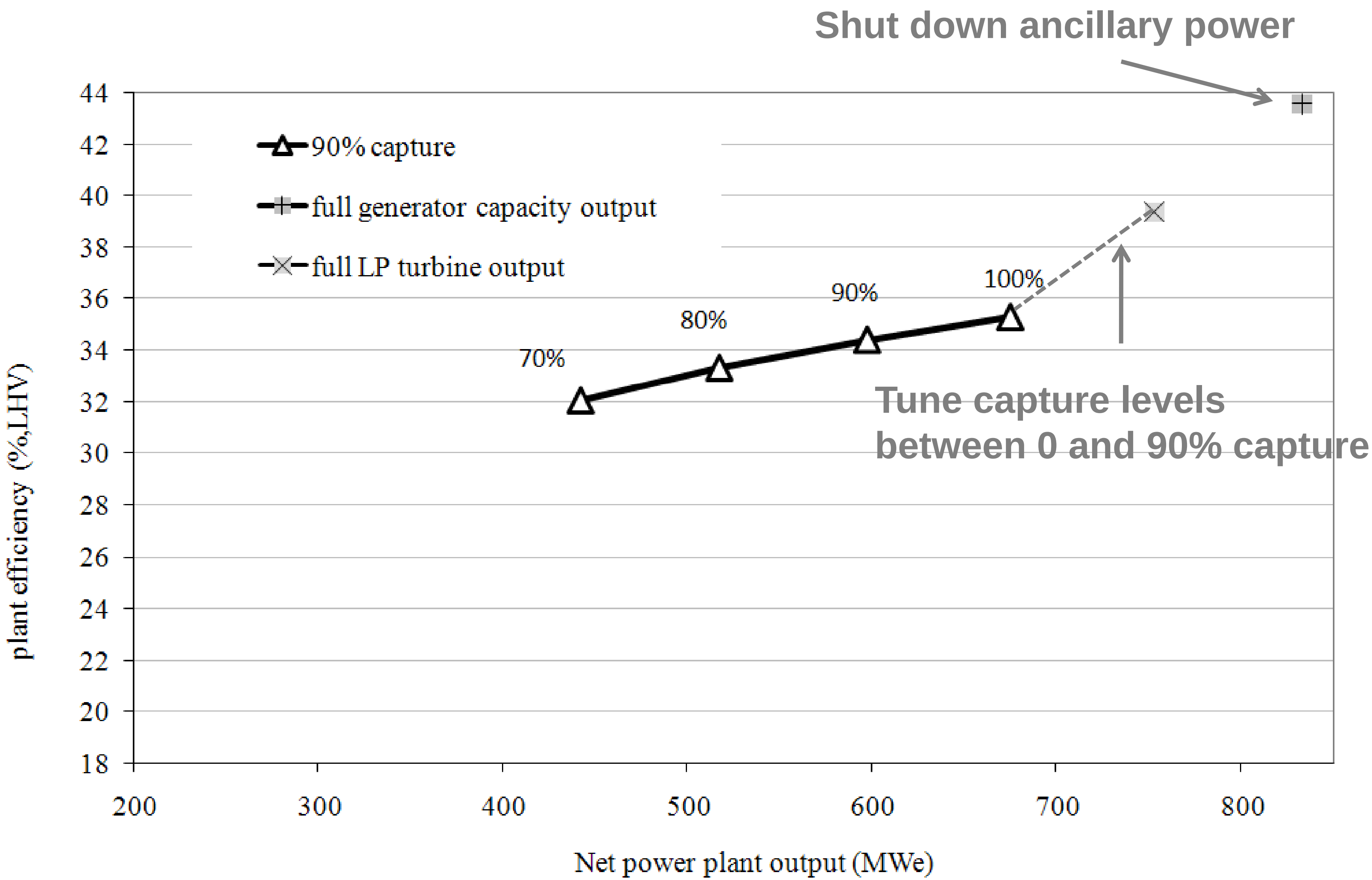
Illustrative example of arbitrage between carbon and electricity prices for full bypass of the CO_2 capture unit

Plant output	750 MW
Coal price	£1.4/GJ
Carbon price	£25/tCO_2
CO_2 transport & storage	£5.5/tCO_2



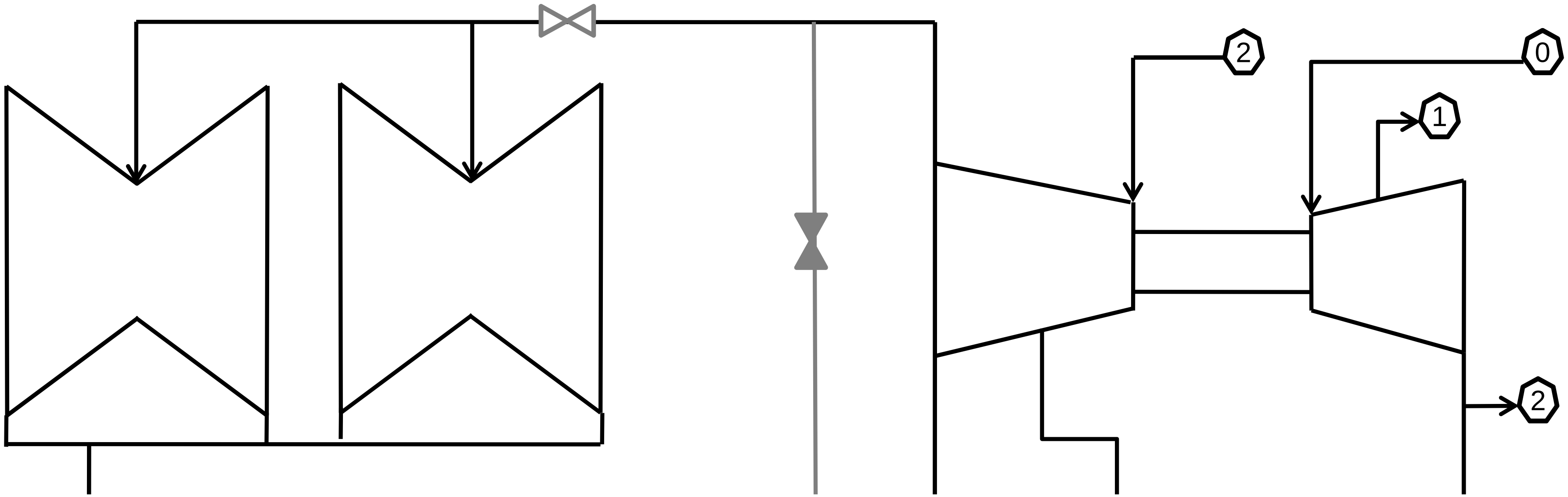
Chalmers H, Gibbins J, Fuel (2007)
Updated in forthcoming report for IEA Clean Coal Centre

Performance at part-load and with absorber voluntary by-pass



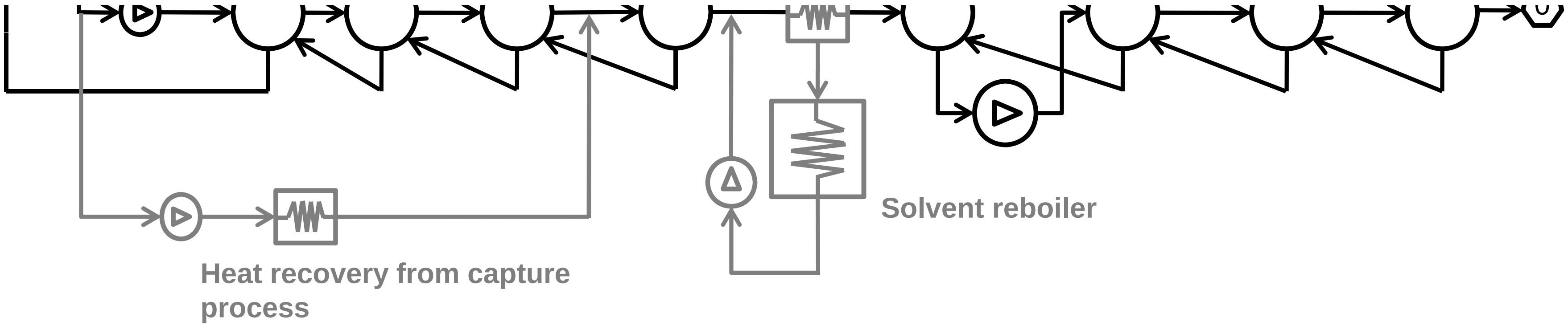
Lucquiaud M, Chalmers H and Gibbins J, Energy Materials 2008 2(3), 177-183

Voluntary absorber by-pass

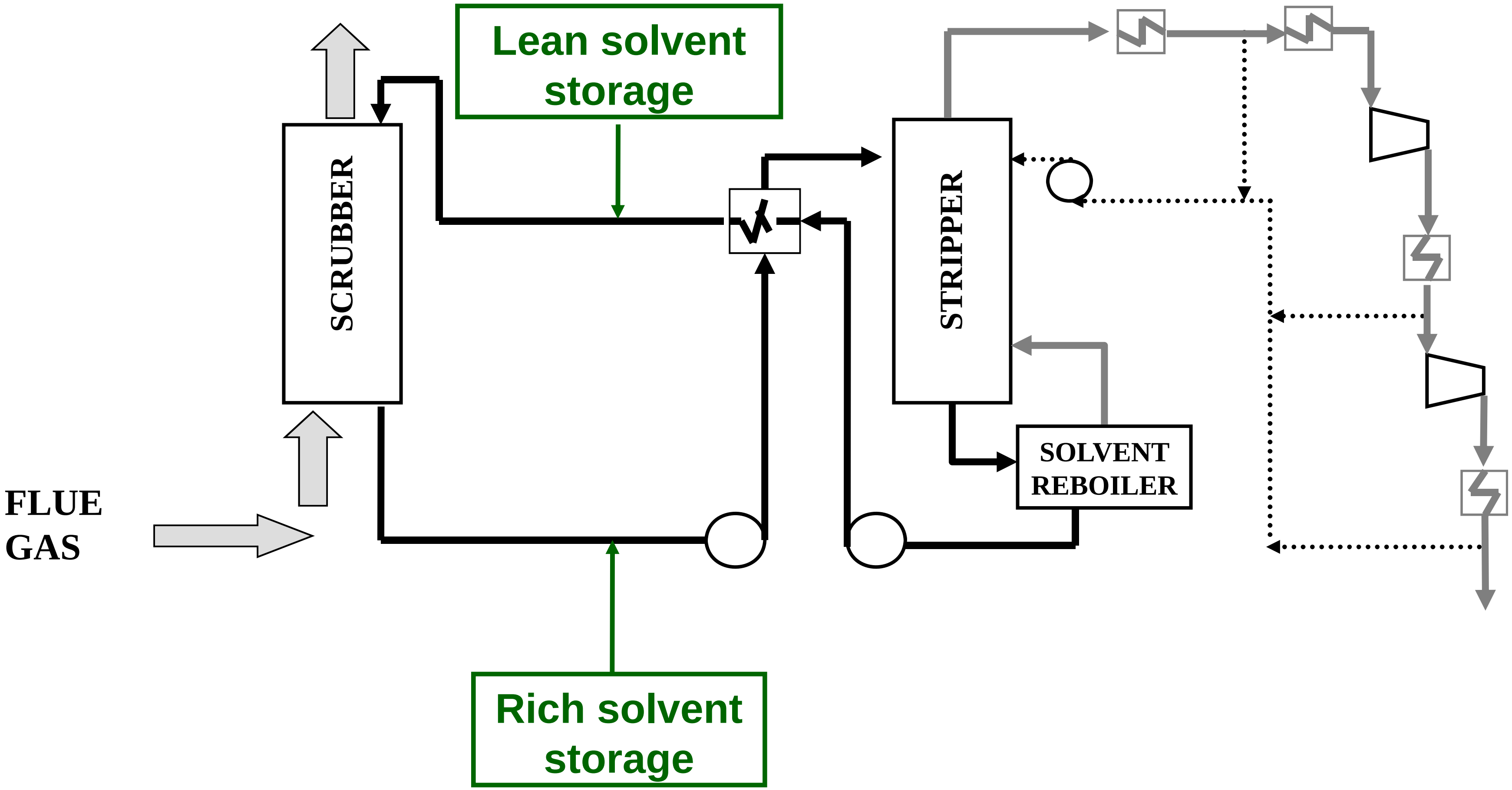


❑ **<u>NEW-BUILD UNITS</u>: Oversize generator capacity and low pressure turbines to export additional power available**

❑ **<u>RETROFITS:</u> return to initial power output**

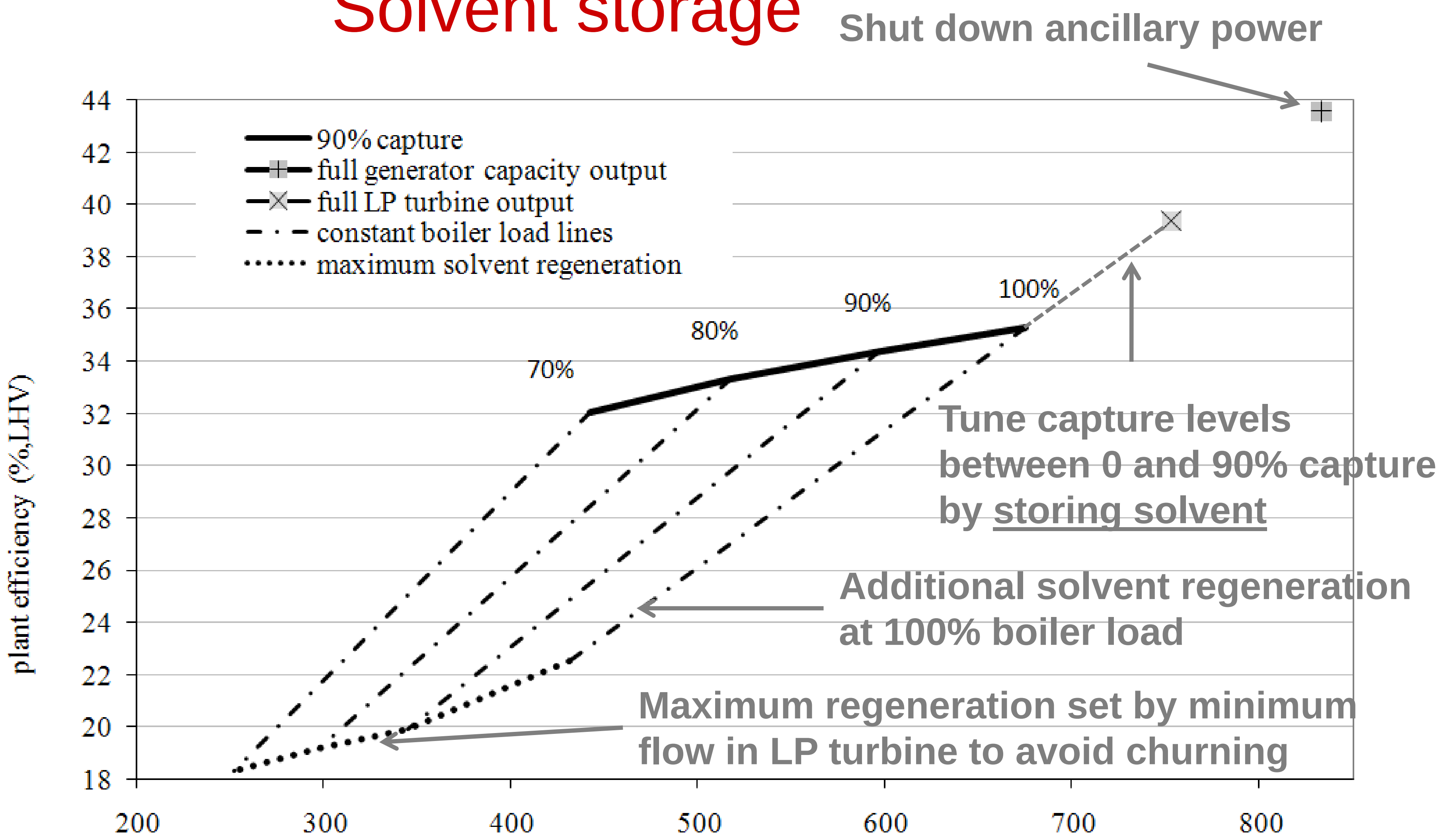


Solvent storage



- ❑Space requirement will depend on number of hours of solvent storage capacity
- ❑Impacts of solvent degradation.
- ❑Implications for environmental permitting

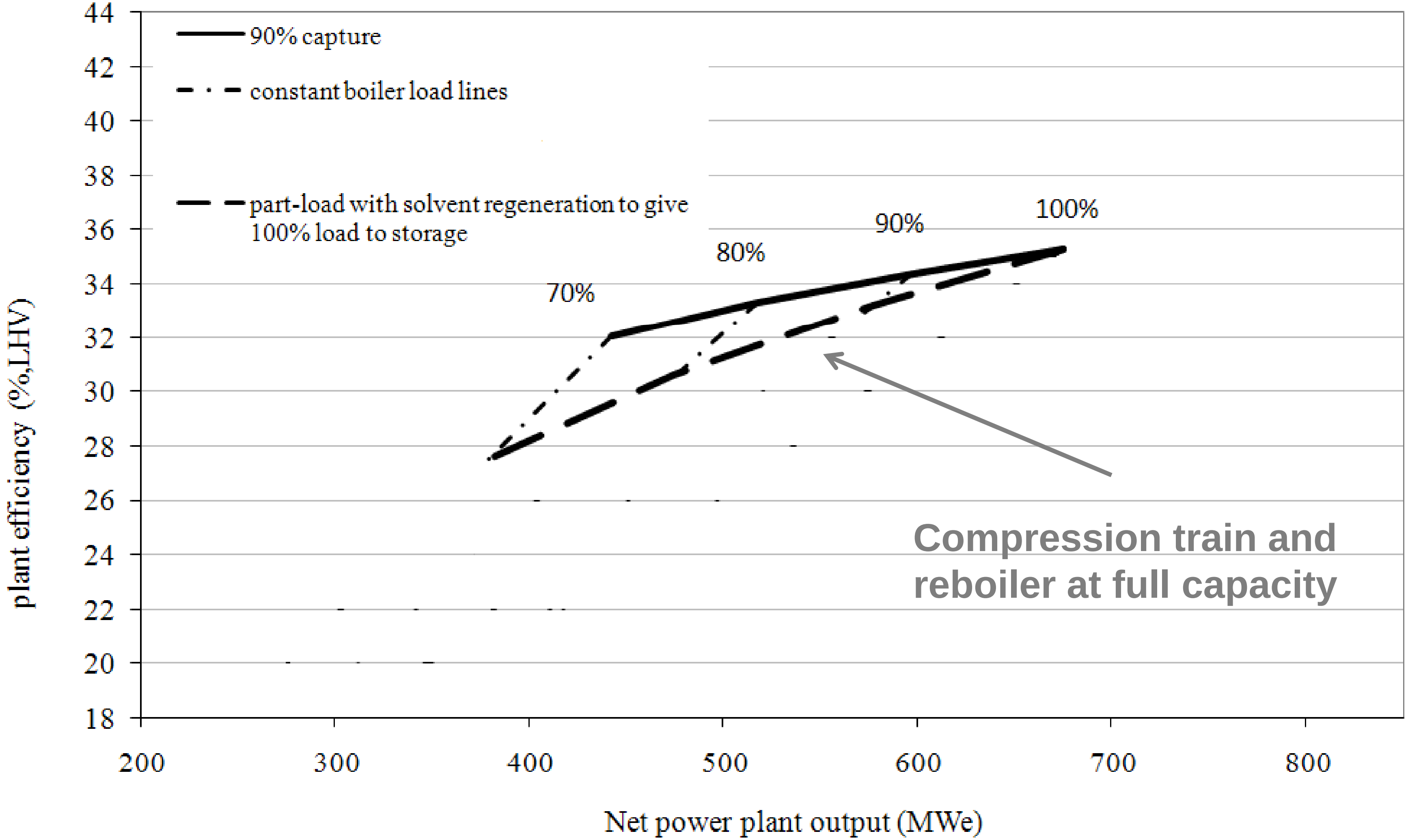
Solvent storage



❑**Investment decision: Oversize stripper, reboiler and compression train for additional regeneration?**

Lucquiaud M, Chalmers H and Gibbins J, Potential for flexible operation of pulverised coal power plants with CO_2 capture, Energy Materials 2008 2(3), 177-183

Solvent storage without oversizing regeneration



- **Times to regenerate 1hr of solvent:**
- **At 80% load > 5hrs**
- **At 70% load 3.5 hrs**

- Additional investment costs need to be defined, but baseline will vary
  - Bypass: Extra capacity ‘free’ for some retrofits, but additional for new-build
  - Solvent storage: Solvent inventory and tanks, also additional stripper/reboiler and compressor capacity for ‘aggressive’ options

- Need to consider range of plausible future scenarios for electricity selling price
- Value of ancillary (support) services could also become more important in future networks

Future-proof upgrading flexibility

- Incorporate future improvements in an area of technology change
- Future-proof your asset against 2nd and 3rd generation of CCS plants
- Difficult to predict solvent developments 10-20 years in advance

Future-proof upgrading flexibility

- Possible reasons for a solvent upgrade
  - Reduce fuel costs: More power out of steam cycle and/or lower ancillary power
  - Reduce solvent costs: “cheaper” molecules, reduced inventory, reclaiming, degradation
  - Reduce emission costs: higher capture rate per unit of electricity

Future-proof upgrading flexibility

- With the same pieces of equipment
  - Faster kinetics: reduce the irreversibilities of absorption => lower the energy of regeneration
  - Favourable VLE: lower energy of regeneration and/or higher stripper operating pressure => reduced compression power, increased levels of capture

Future-proof upgrading flexibility

- Faster kinetics => flexibility in the absorber design
- Favourable VLE

  => flexibility in reboiler design

  => flexibility in compressor design

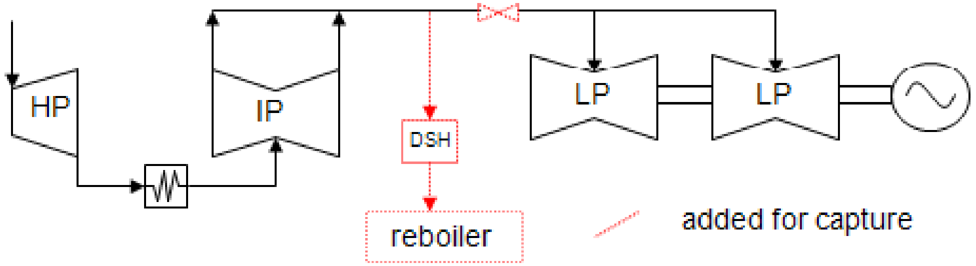
  => flexibility in the steam turbine design to accommodate for changes in

  - Steam extraction flowrate
  - Temperature of regeneration
- What does a future-proof steam turbine design look line?

Capture-ready steam turbine designs and consequences for integration

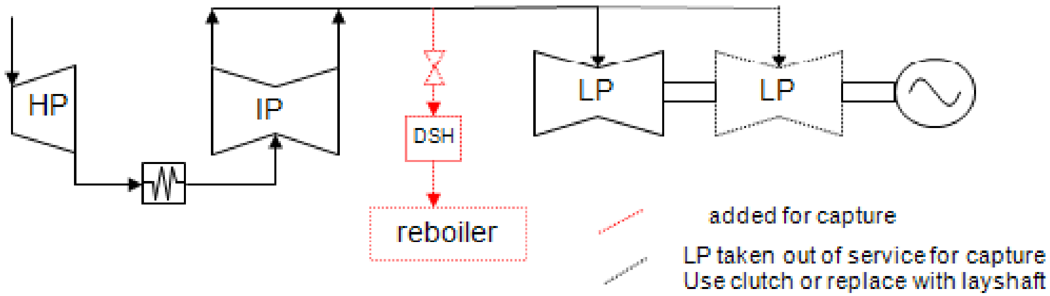
Lucquiaud et al, IEA GHG 2007-4; Proc. IMechE Vol. 223 Part A3: J. Power and Energy, May 2009, p213 & p227

• Throttled LP turbine



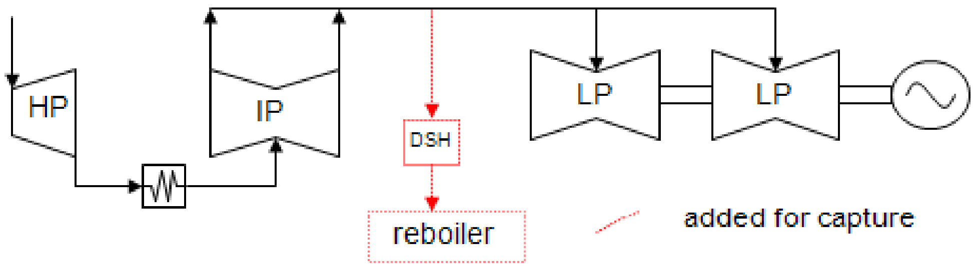
Simplest design, but losses in throttling valve. Initial pressure ~3.6 bar for amine, cannot be varied

• LP turbine taken out of service



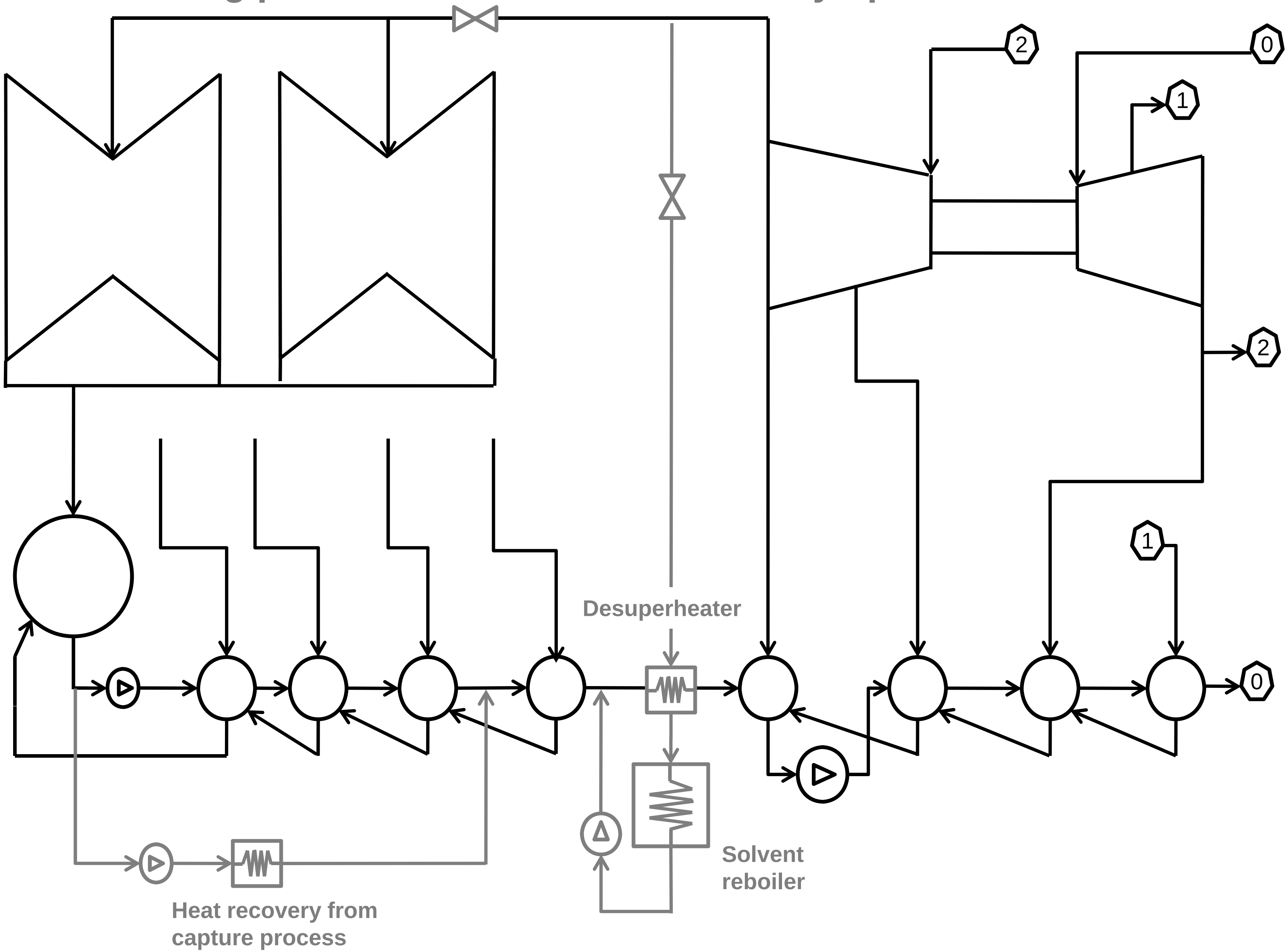
Most efficient design, but cannot vary steam extraction flow. Initial pressure ~3.6 bar for amine, cannot be varied

• Floating IP/LP crossover pressure

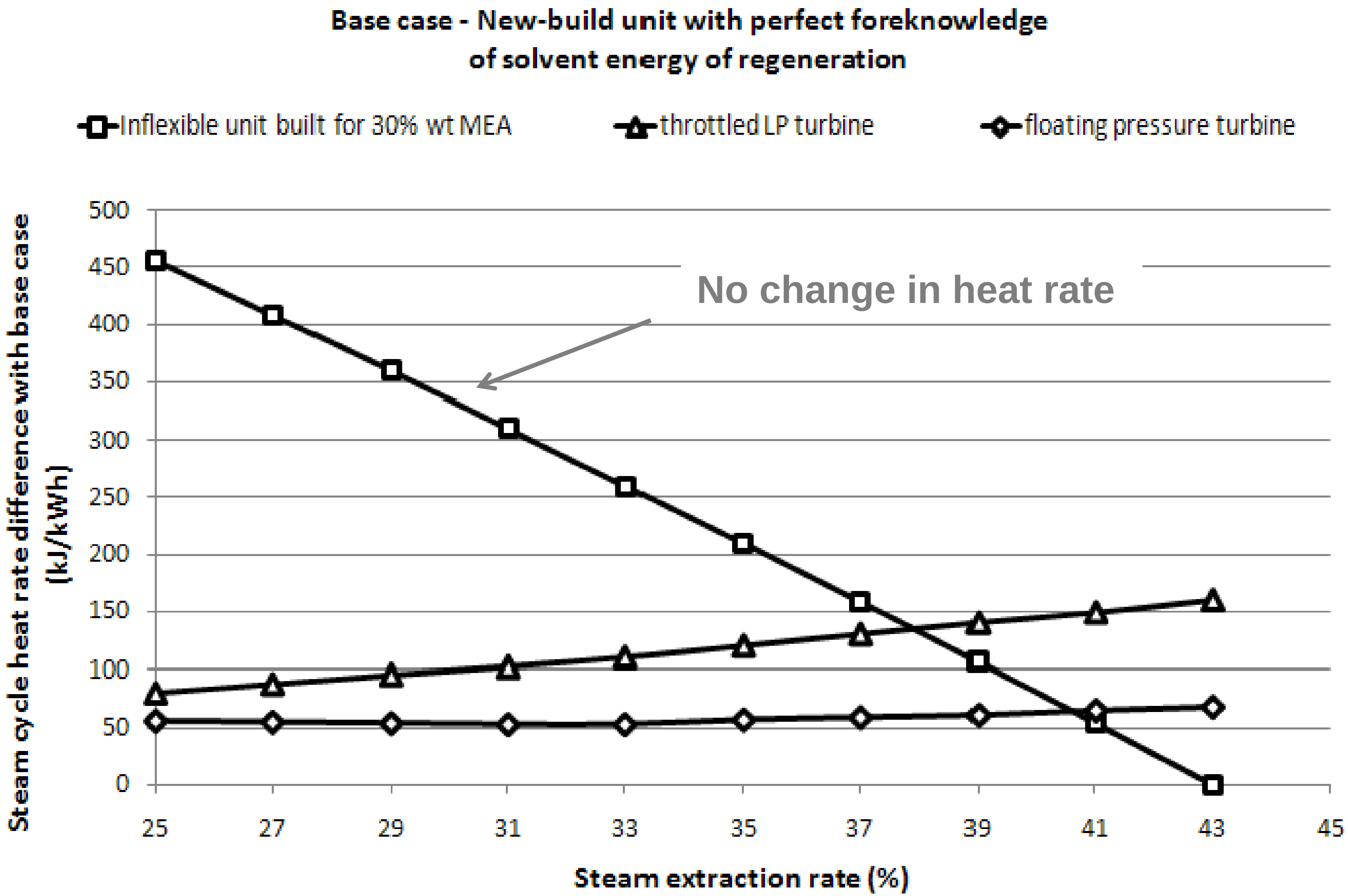


Avoids all throttling losses at design extraction rate. Extraction pressure goes up with reduced flow rate 7 to 3.6 bar possible

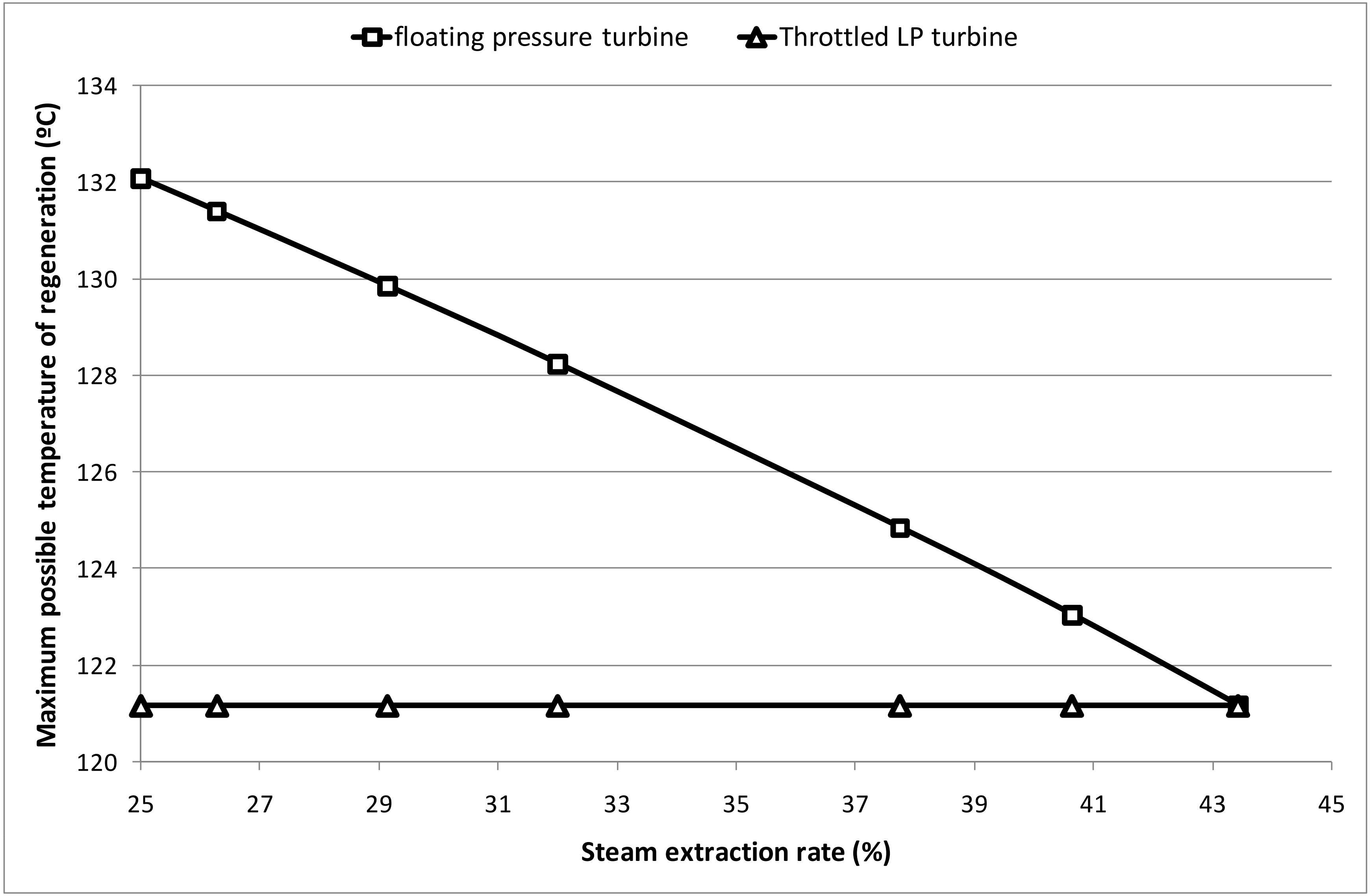
Floating pressure – Valve at LP inlet fully open for base load



Comparison of capture-ready steam turbine options for a range of solvent energy of regeneration – same reboiler temperature



Maximum possible regeneration temperature for solvent with reduced energy of regeneration



Conclusions

- Operating flexibility requires oversizing LP turbine and generator for maximum power output.
- “Aggressive” solvent storage strategy needs oversizing reboiler and compression train.
- For future proof upgrading flexibility steam delivery pressure to solvent reboiler need to be able to change
- Consider floating pressure turbine system for both upgrading and operating flexibility
- Convergence between steam turbine design for capture-ready and new-build units
- Further work needed on compression operation at part-load