Chemical Models and Energy Balance for Optimal Gas Utilisation

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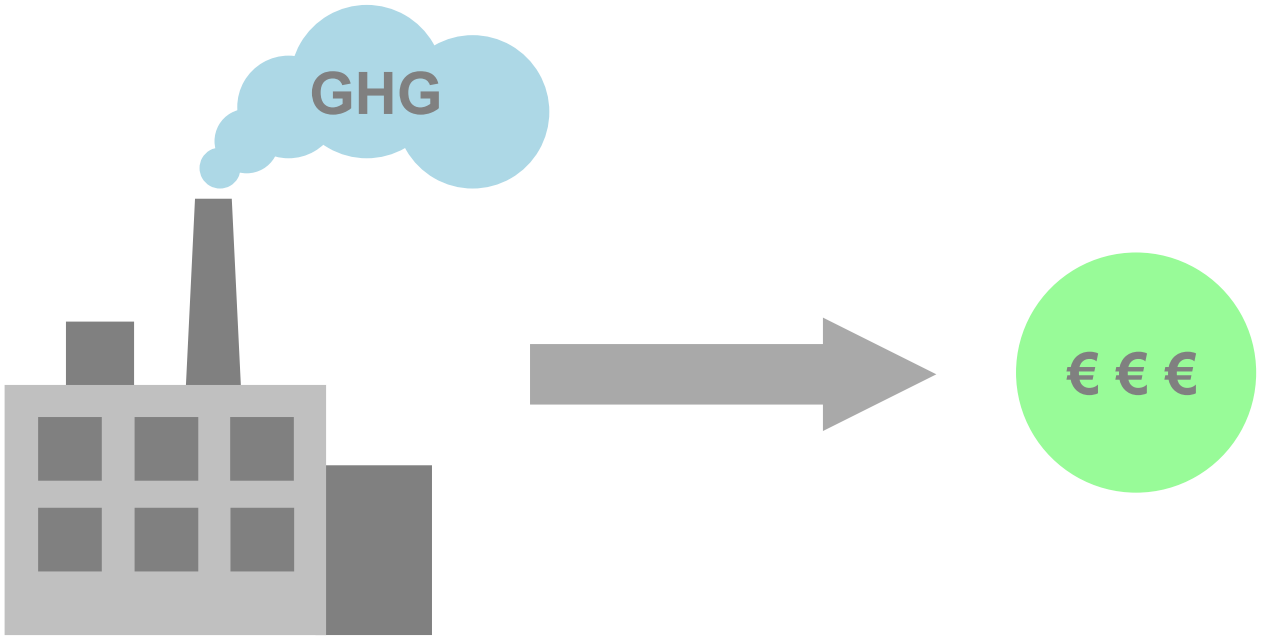
Contents

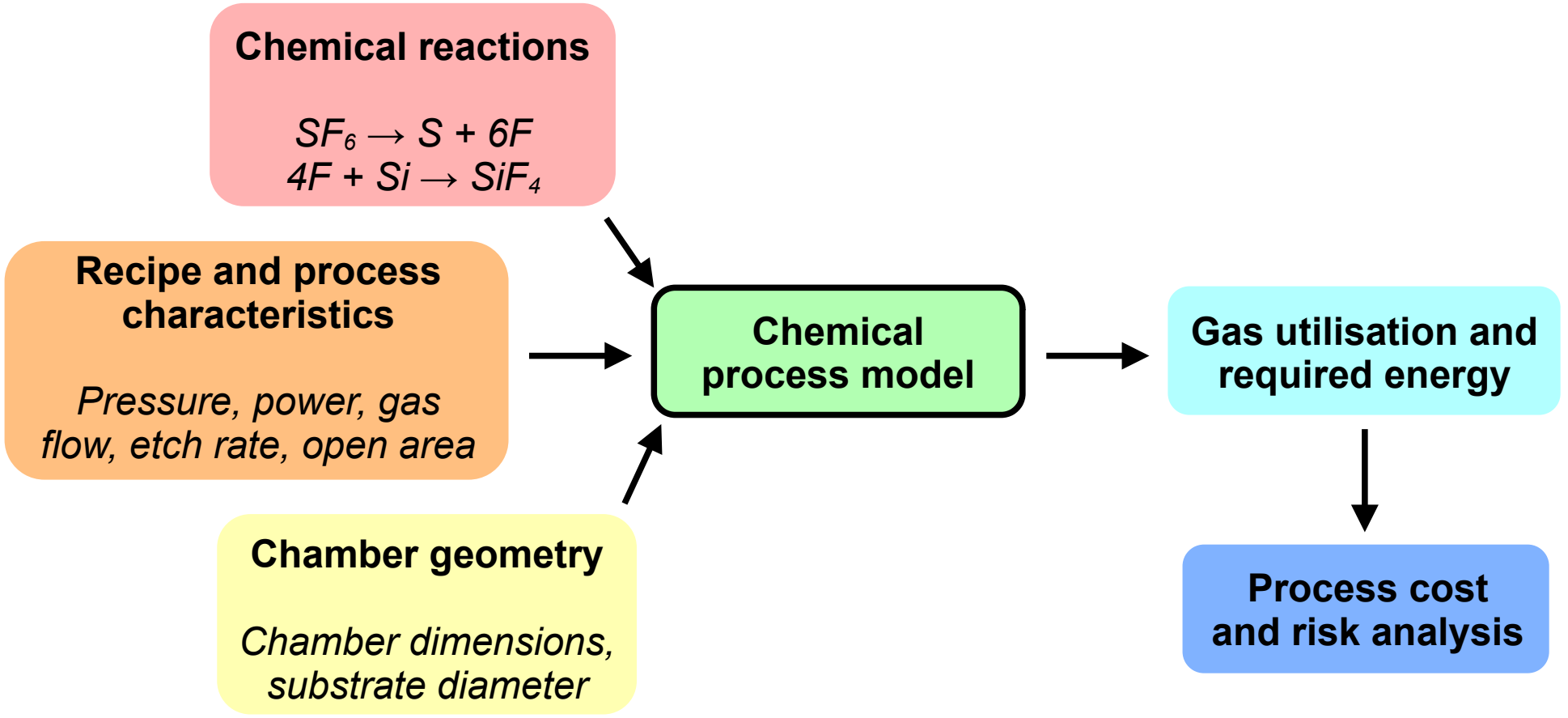
Motivation

- Semiconductor fabs must reduce greenhouse-gas emissions while maintaining performance.



- Chemical process models help us optimise gas usage while maintaining process stability.

Chemical Process Model



Chemical Process Model: Example

Reaction:	Si etch with SF_6

→ Dissociation of SF_6

Process:	Demo,Trench:ResistMask:1%
	800 sccm, 3.5kW, Si etch
ER / Depo rate [nm/min], Open area =	{5299.65, 0.01}
$p_{Chamber}$ [Pa], P_{source} [W] =	{3.325, 3500}
Inward flux of process gas SF6 [sccm] =	800

→ DRIE recipe (Etch rate of the Si-etch step only)

Chamber:	SPTS Rapier 200 mm
Substrate diameter [mm] =	200.

→ Chamber dimensions

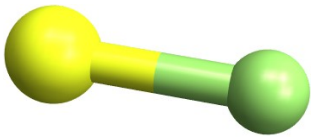
Amount of radicals consumed →

Process gas flux directly used SF6 [sccm] =	2.08
Utilization factor process gas SF6 [%] =	0.26
Energy per molecule P_{source} / $I_{gas,total}$ [eV] =	61.1

Chemical Process Model: Energy for Dissociation

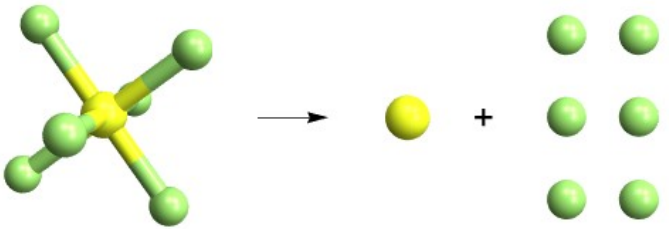
- Source power determines the degree to which the process gas dissociates.

Chemical bonds



Mean bond energy
3.3 eV

Dissociation



Dissociation energy
19.8 eV

System losses

Matchbox, coil, etc.

Power loss
30%

Required energy

Energy per molecule
28.3 eV

Chemical process model

Energy per molecule P_{source} / $I_{gas,total}$ [eV] = 61.1

Chemical Process Model: Open Area

- Only a fraction of incoming gas actually reacts on the wafer.

Small open area

ER / Depo rate [nm/min], Open area =	{5299.65, 0.01}
$p_{Chamber}$ [Pa], P_{source} [W] =	{3.325, 3500}
Inward flux of process gas SF6 [sccm] =	800

Process gas flux directly used SF6 [sccm] =	2.08
Utilization factor process gas SF6 [%] =	0.26

Radicals are oversupplied
Surface-reaction-controlled process

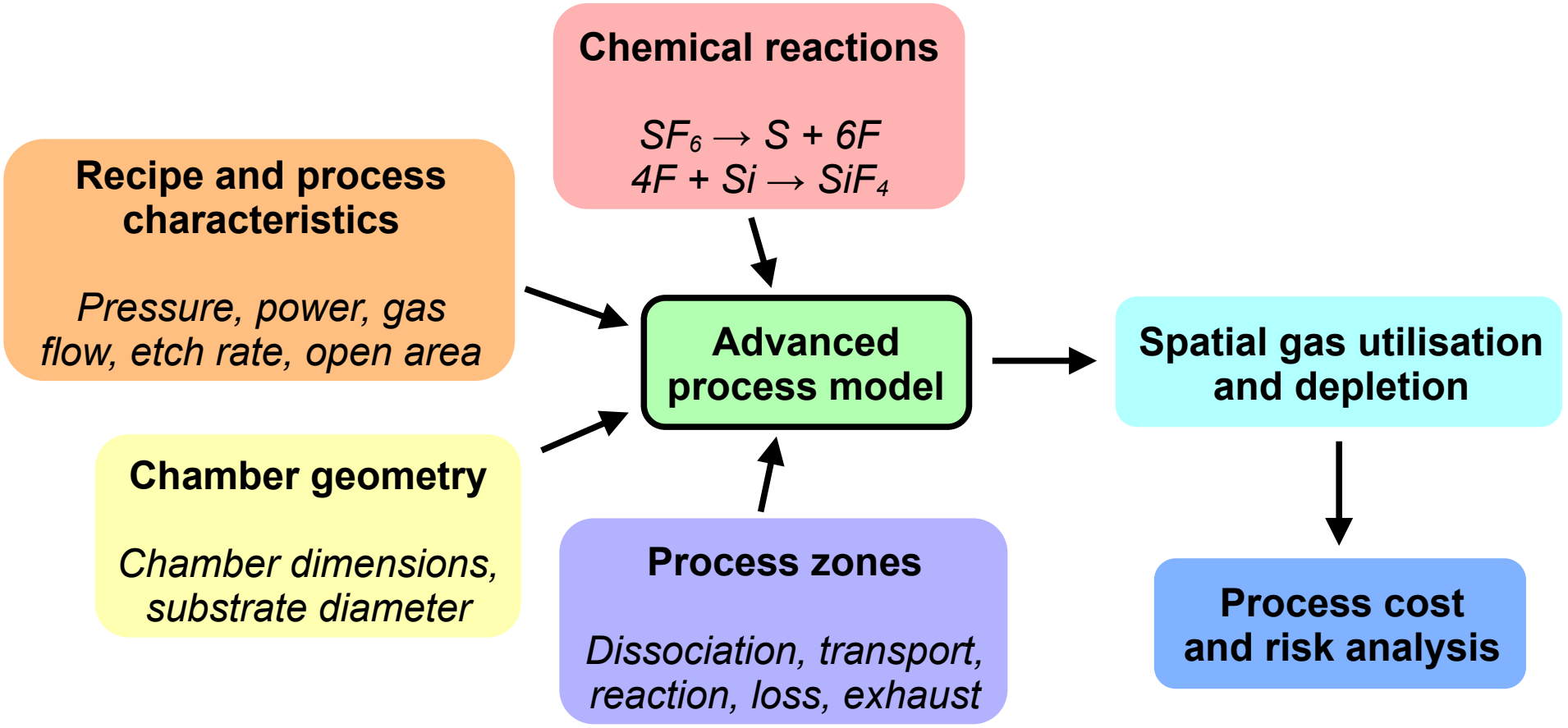
Large open area

ER / Depo rate [nm/min], Open area =	{16 224.5, 0.68}
$p_{Chamber}$ [Pa], P_{source} [W] =	{3.325, 3500}
Inward flux of process gas SF6 [sccm] =	800

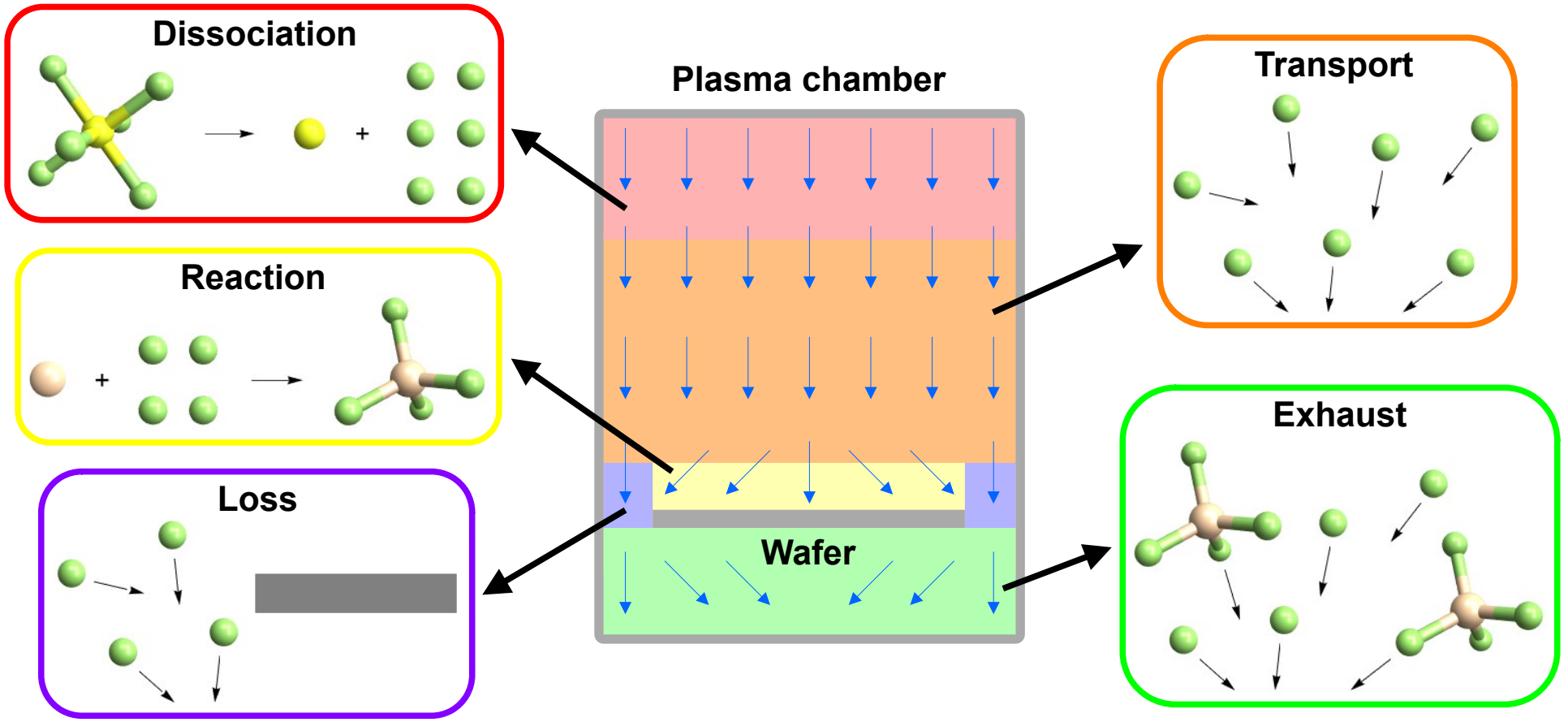
Process gas flux directly used SF6 [sccm] =	432.
Utilization factor process gas SF6 [%] =	54.

Radicals are depleted
Transport-controlled process

Advanced Process Model



Advanced Process Model: Process Zones



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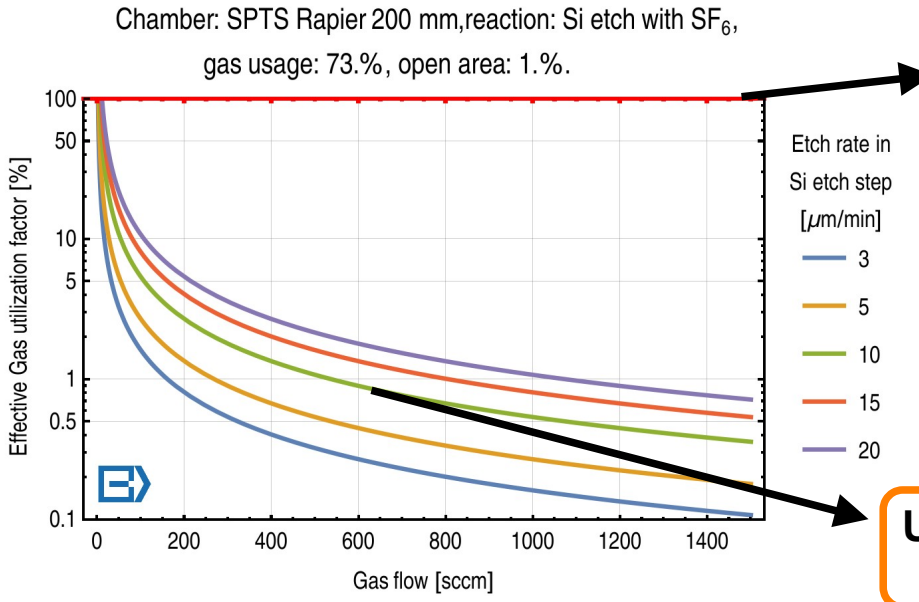
Advanced Process Model: Example

- The graph shows how gas utilisation and etch rate depend on gas flow.



Utilisation limit
Theoretical maximum

Perfect gas utilisation, operation below the limit

Flat region
Surface-reaction-controlled regime

Utilisation curve slope
Regime indicator

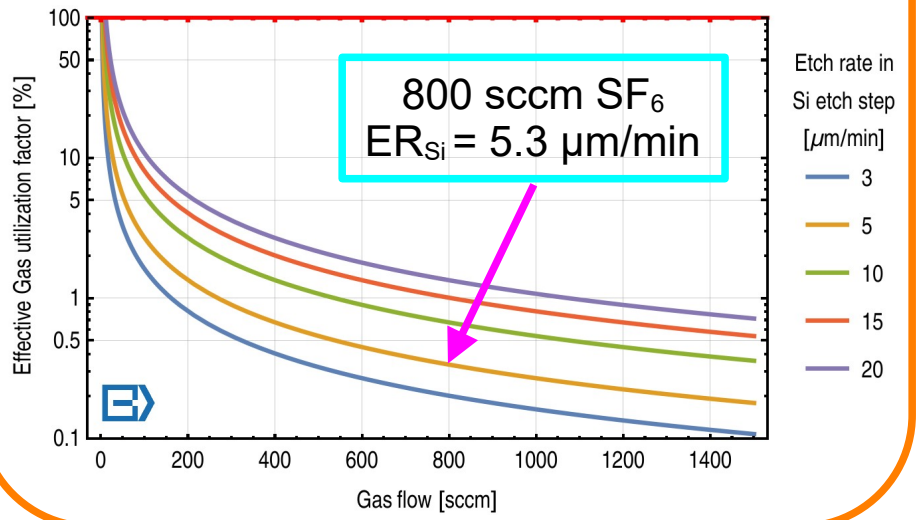
Transition region
Efficient operating regime

Steep region
Transport-controlled regime

Advanced Process Model: Open Area

Small open area

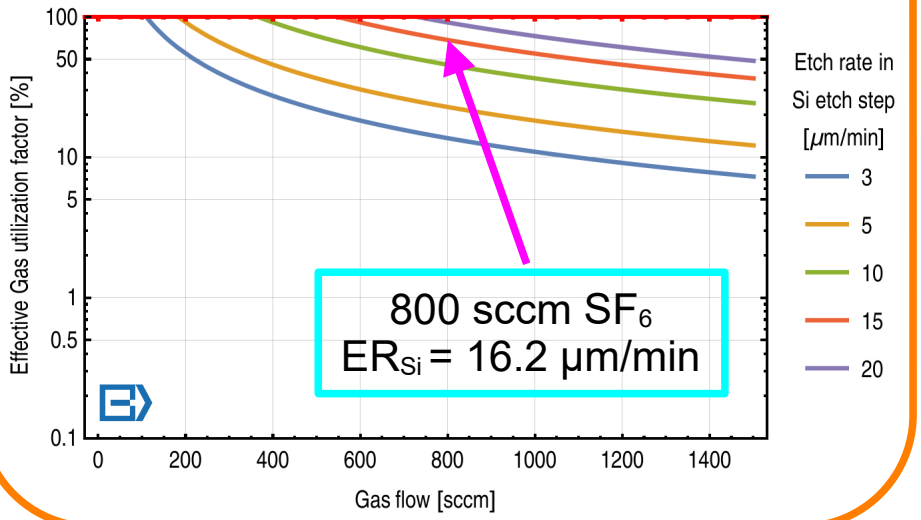
Chamber: SPTS Rapier 200 mm,reaction: Si etch with SF_6,
gas usage: 73.%, open area: 1.%.



Surface-reaction-controlled process

Large open area

Chamber: SPTS Rapier 200 mm,reaction: Si etch with SF_6,
gas usage: 73.%, open area: 68.%.



Transport-controlled process

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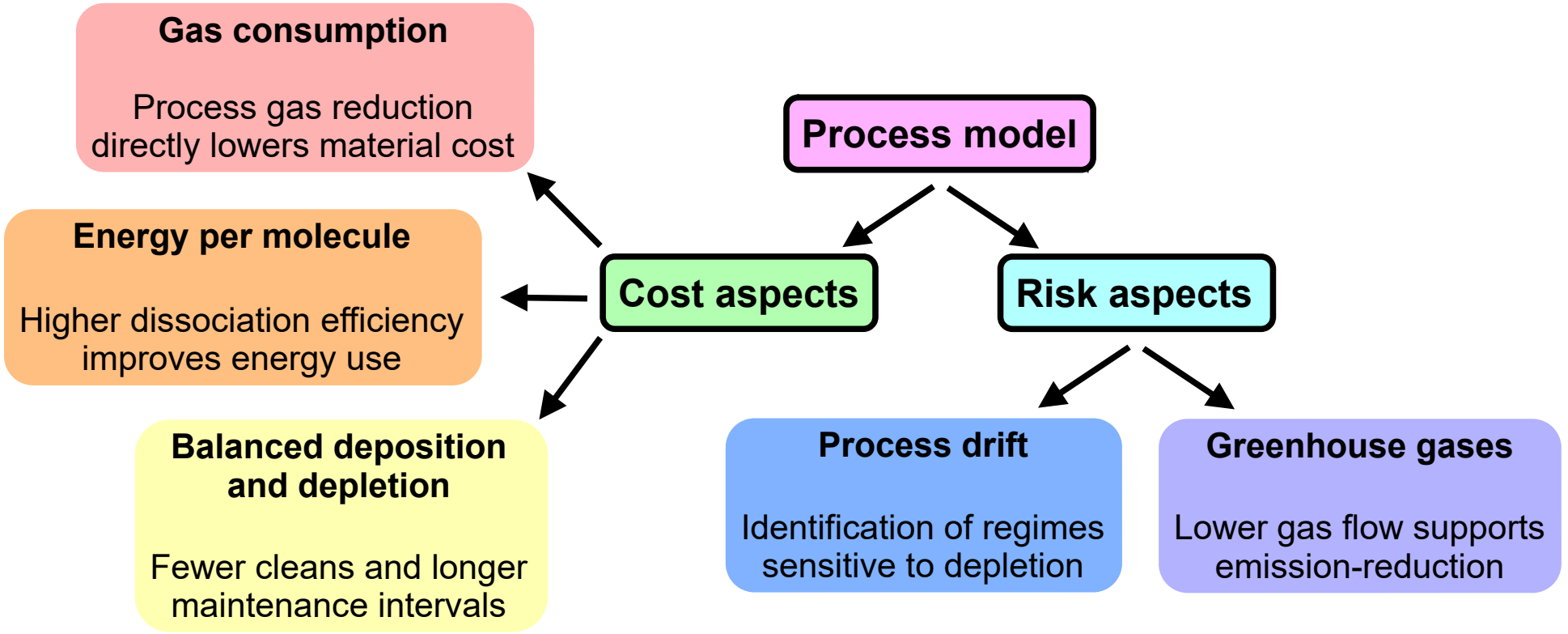
Process Cost and Risk Analysis

- The process models link gas utilisation directly to cost and risk.



Summary

- The chemical process model links recipe parameters, chamber geometry, and reaction chemistry to predict gas utilisation and energy efficiency.
- The advanced process model adds spatial zones and transport effects, identifying oversupply and depletion regimes.
- These models explain the opposite behaviour observed for small and large open areas.
  - Small → surface-reaction-controlled, oversupply
  - Large → transport-controlled, depletion
- The model results show that gas flow can be reduced without reducing etch rate, lowering both process cost and greenhouse-gas emissions.

Thank you for your attention.

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