Energy saving in semiconductor manufacturing as design goal

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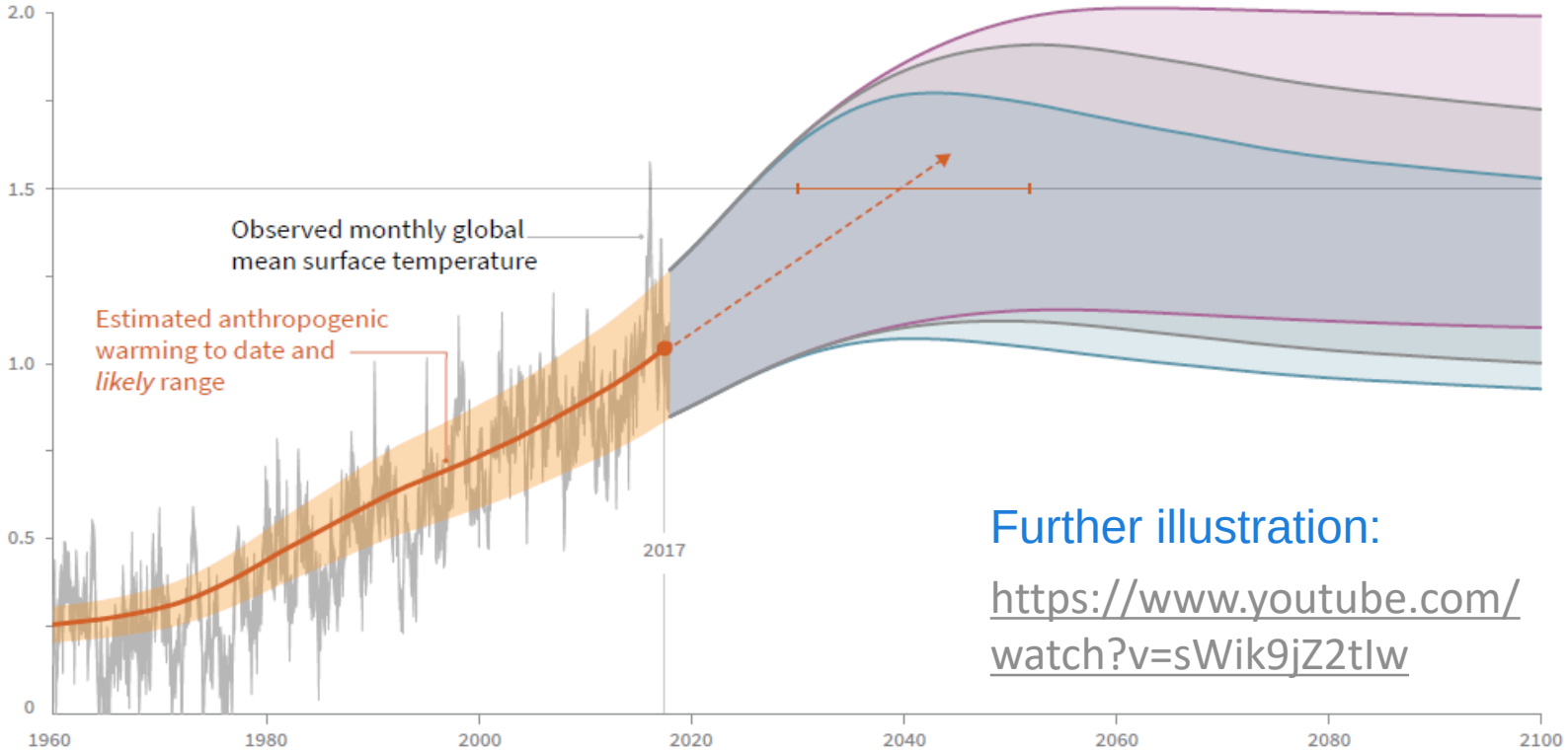
System Engineering

Veldhoven, 5 February 2020

A personal anecdote…

Important graph from October 2018 IPCC report

Global warming relative to 1850-1900 average



Further illustration:

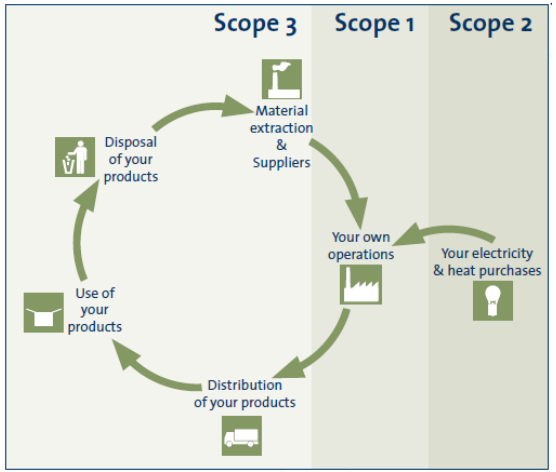
https://www.youtube.com/watch?v=sWik9jZ2tIw

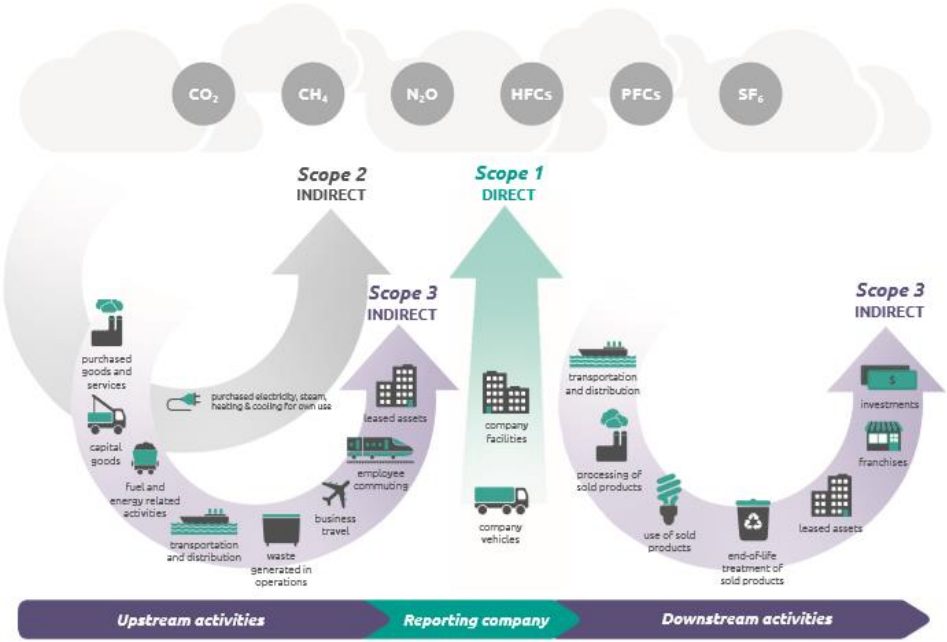
Energy consumption and carbon footprint

"Corporate Quick Scan Analysis" 2010

ASML carbon footprint consists of:

- ~1% direct operations (own emissions, mainly VHV premises), 'scope 1'
- ~5% indirect emissions (power plants delivering electricity & heating), 'scope 2'
- ~94% other: 'Scope 3' → to be reported from 2019!



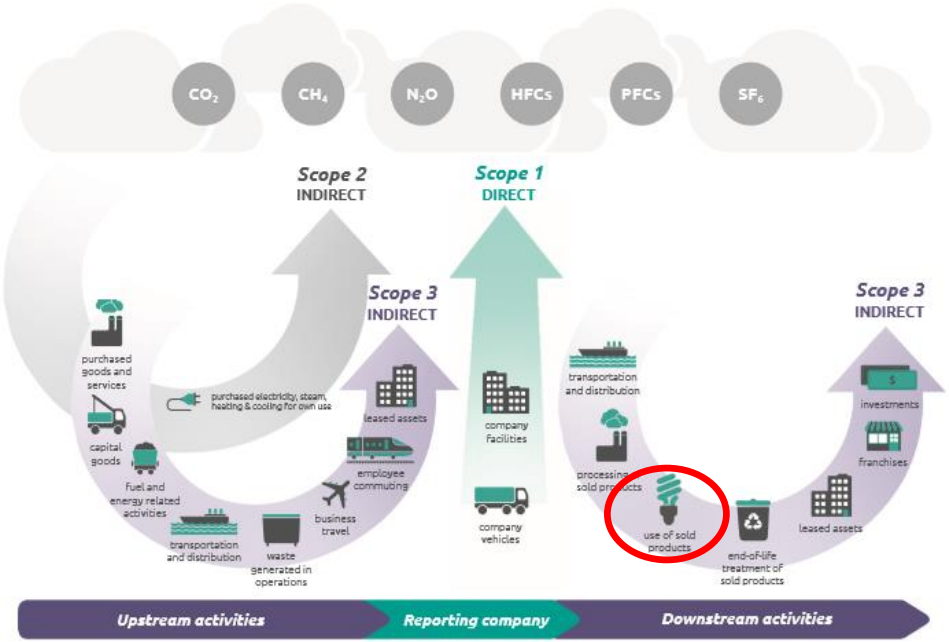


Tool energy use dominates ASML's carbon footprint

"Corporate Quick Scan Analysis" 2010

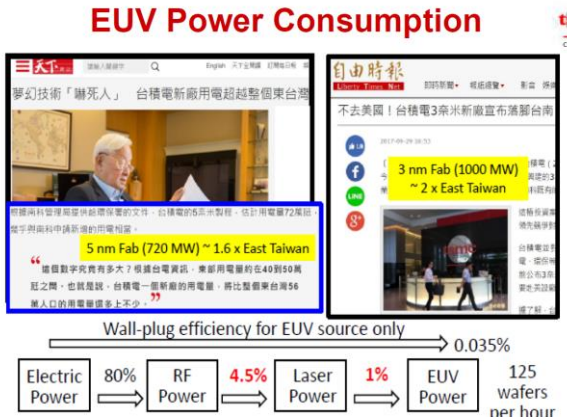
ASML carbon footprint consists of:

- ~1% direct operations (own emissions, mainly VHV premises)
- ~5% indirect emissions (power plants delivering electricity & heating)
- 94% other:
  - supplier manufacturing of parts and modules, employee commuting, business travel
  - **~80% is in-use energy consumption of tools** (note: at time of scan, installed base entirely consisted of NXT; with NXE, this figure rises)



TSMC concerned about EUV Power Consumption

http://english.cw.com.tw/article/article.action?id=1663

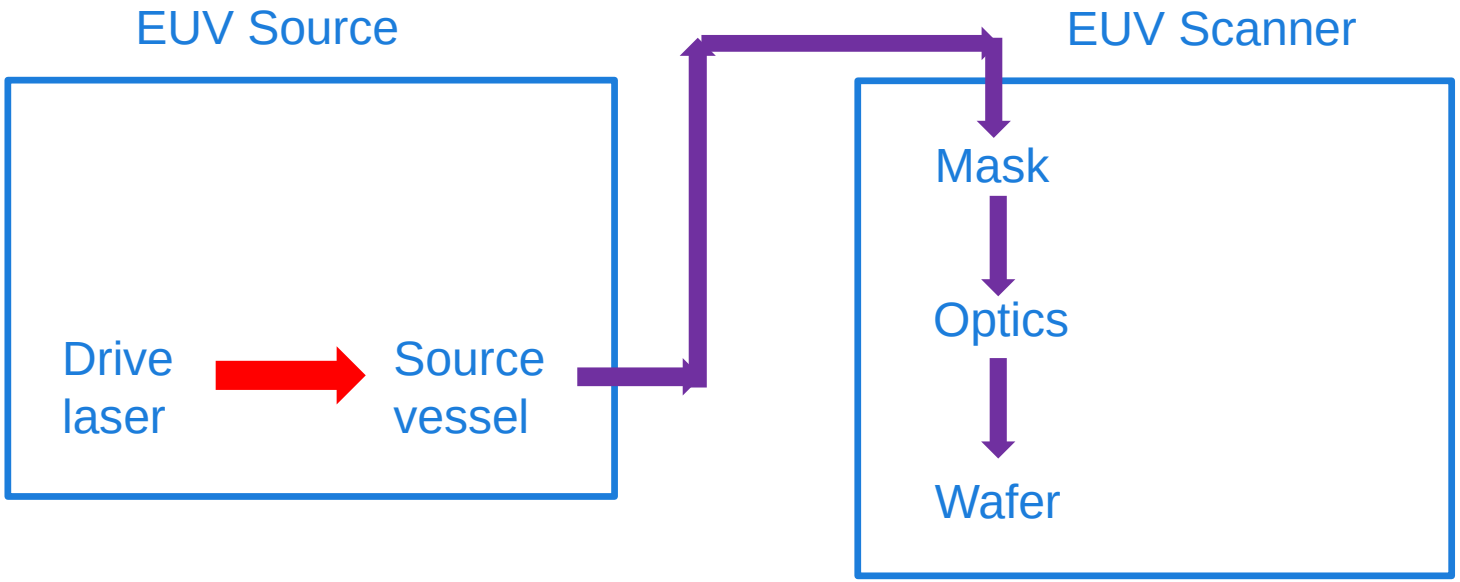


TSMC caused 1/3 of recent power usage increase of Taiwan

In 2017, Tsmc considered building new fab in US due to electricity constraints → update: permission for new fab in Taiwan, provided Tsmc will utilize 20% renewable electricity

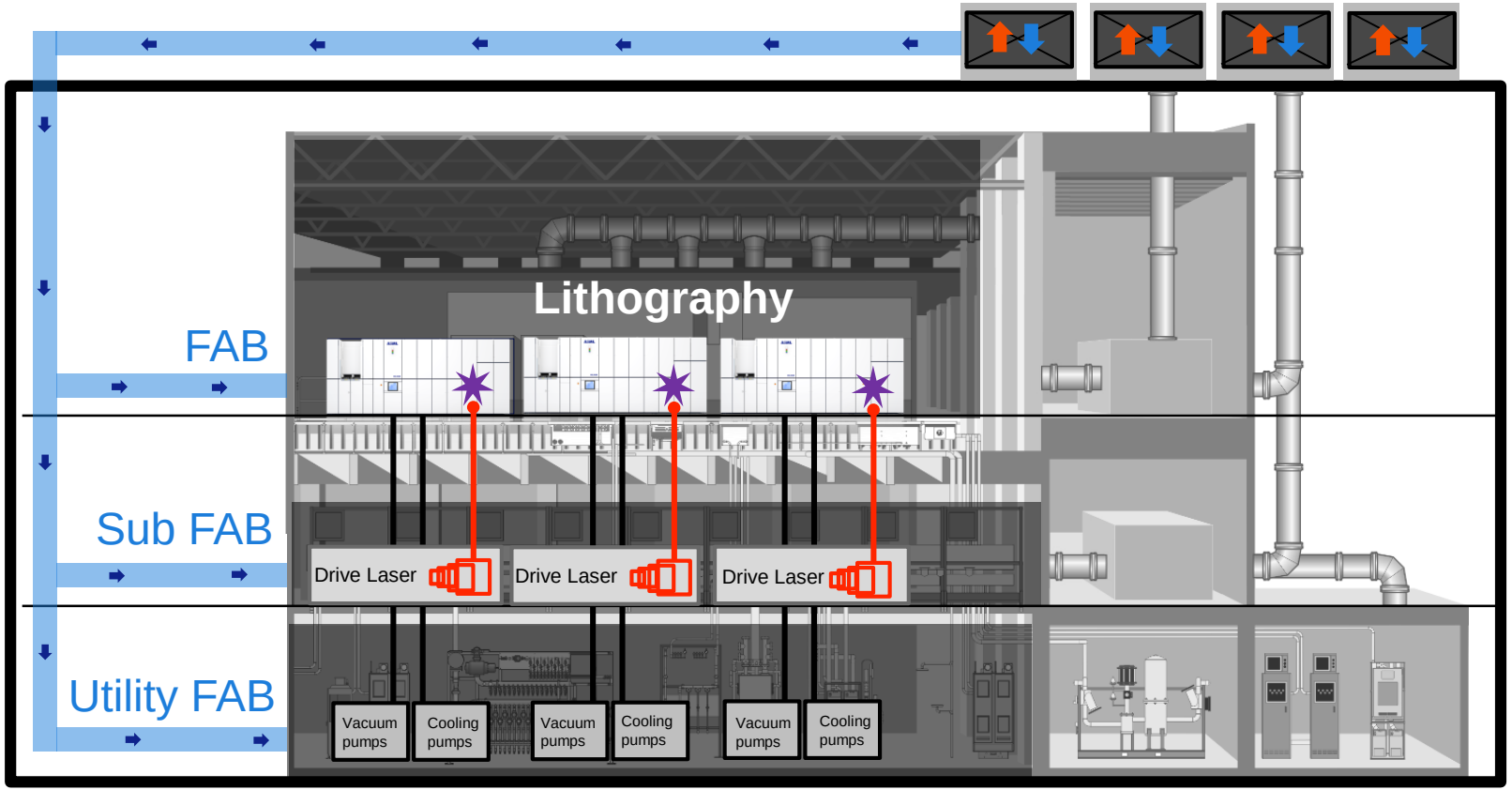
Overview of EUV system configuration

Schematic only



Overview of EUV system configuration

Fab layout



The big picture of system energy flows

Schematic energy diagram of EUV system

Inputs:

- Electrical power
- Chemicals: H_2 and CH_4 (for abatement)
- Facilities: mainly cooling water, clean dry air, N_2, vacuum, exhaust

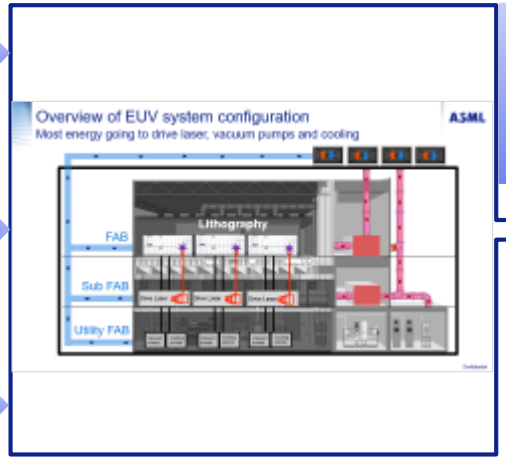
The big picture of system energy flows

Indicative values for NXE:3400

Facilities (ex. PCW)
~ 8%

Electrical power
~ 100%

Chemicals
~ 8%



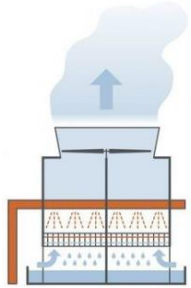
Waste heat
~ 115%

- EUV light ~ 0,03%
- Stage movements ~ O(1%)

The big picture of system energy flows

Indicative values for NXE:3400

= TEE = Total Equivalent Electrical power in (S23)



Rejected heat

~ 135%

Chiller

~ 25%

PCW

PCW heat load

~ 110%

~ 5%

cleanroom, exhaust

Facilities

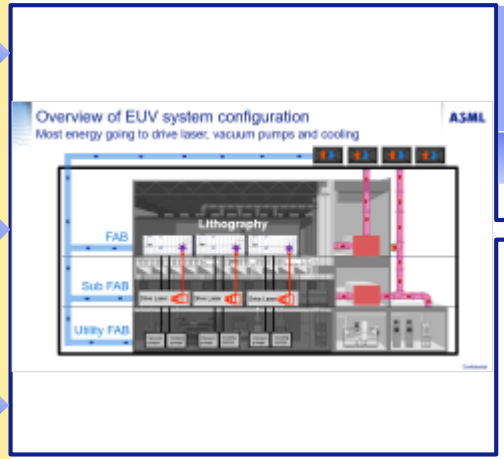
~ 8%

Electrical power

~ 100%

Chemicals

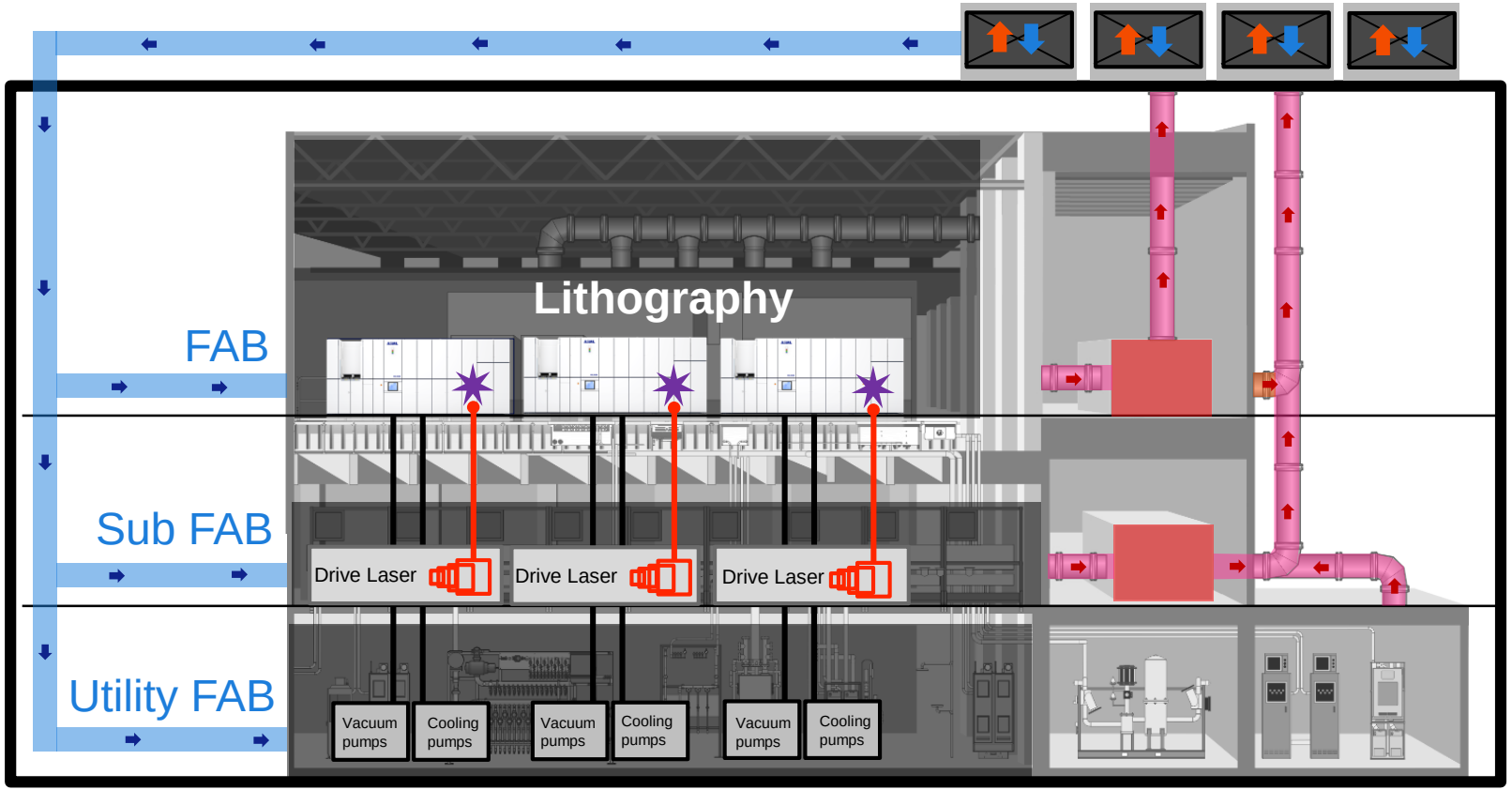
~ 8%



- EUV light ~ 0,03%
- Stage movements ~ O(1%)

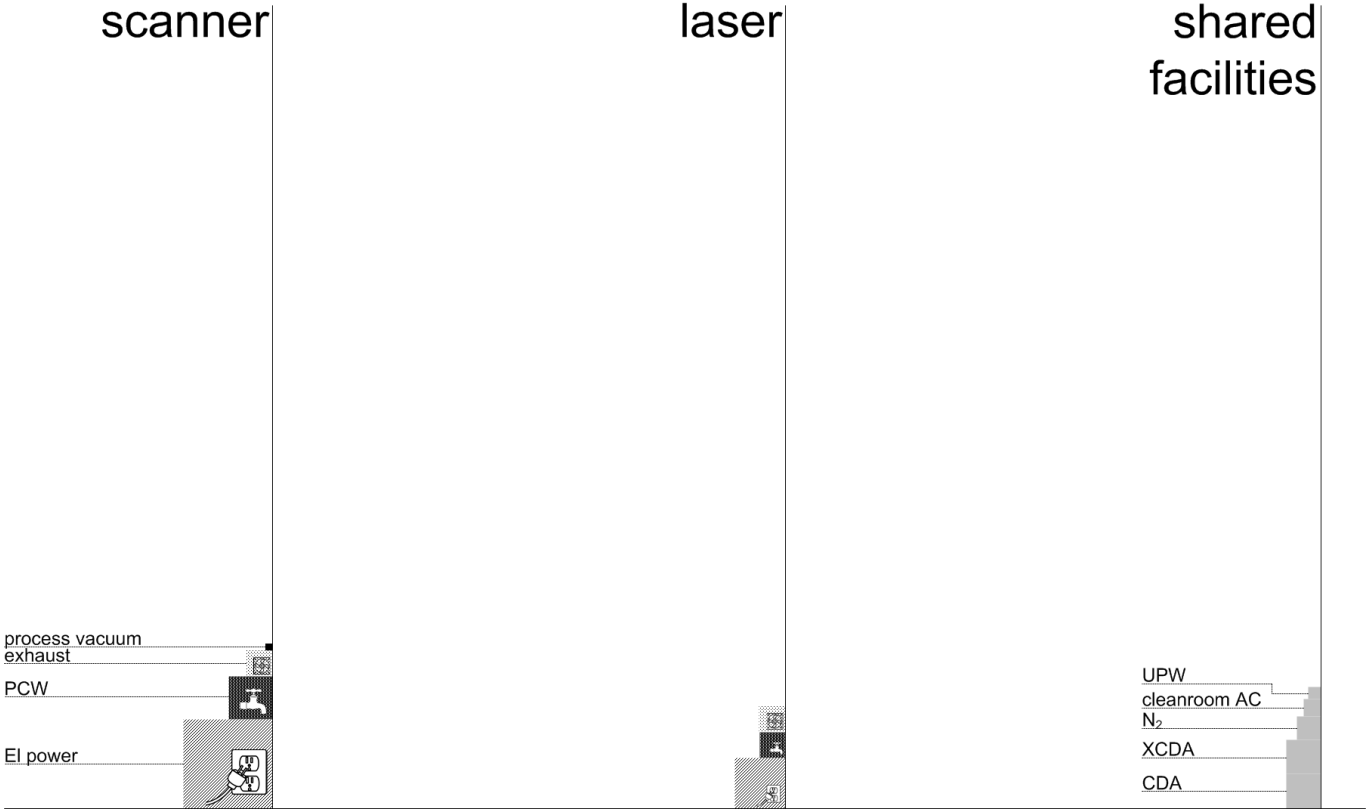
Overview of EUV system configuration

Most energy going to drive laser, vacuum pumps and cooling



EUV facility usage (block sizes are mutually to scale)

Total equivalent energy consumption during lot production



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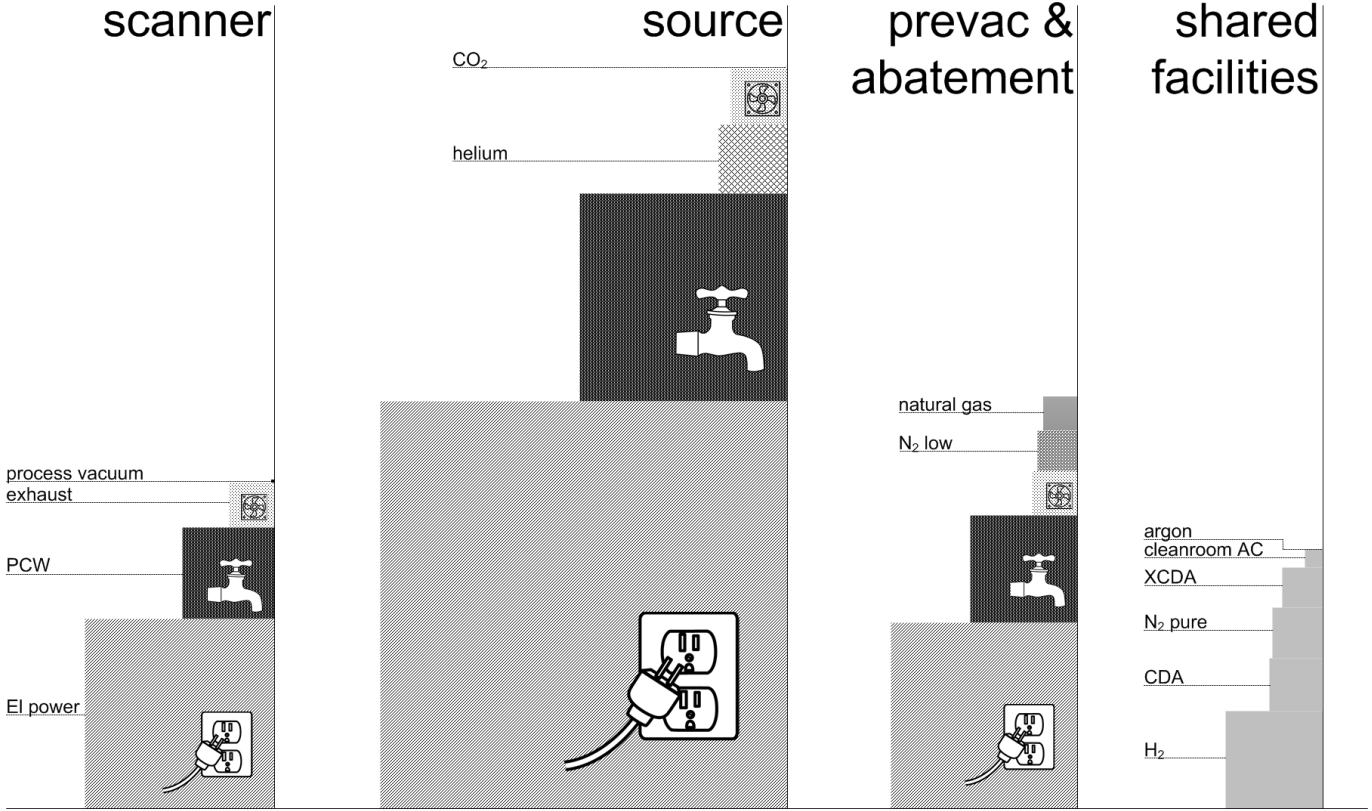
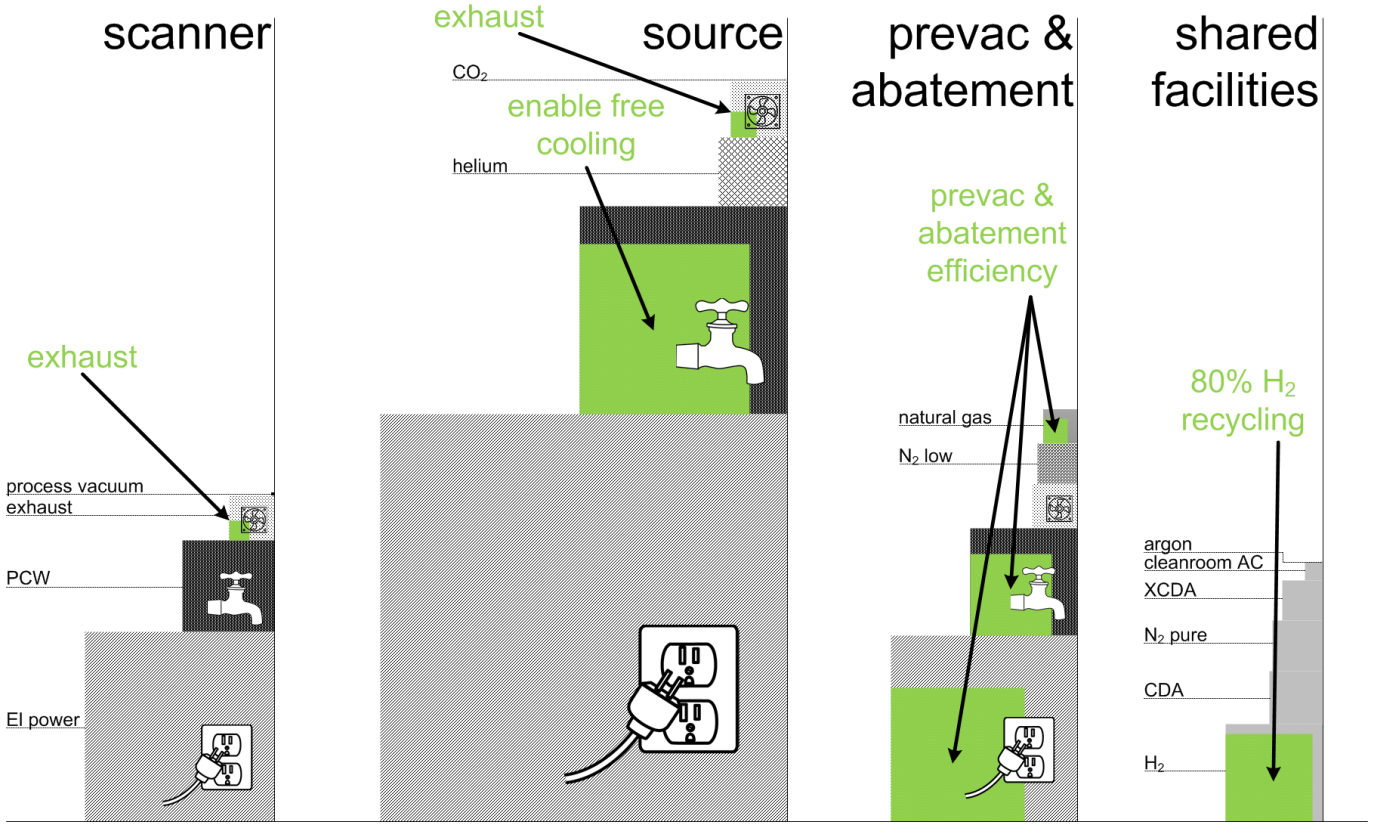


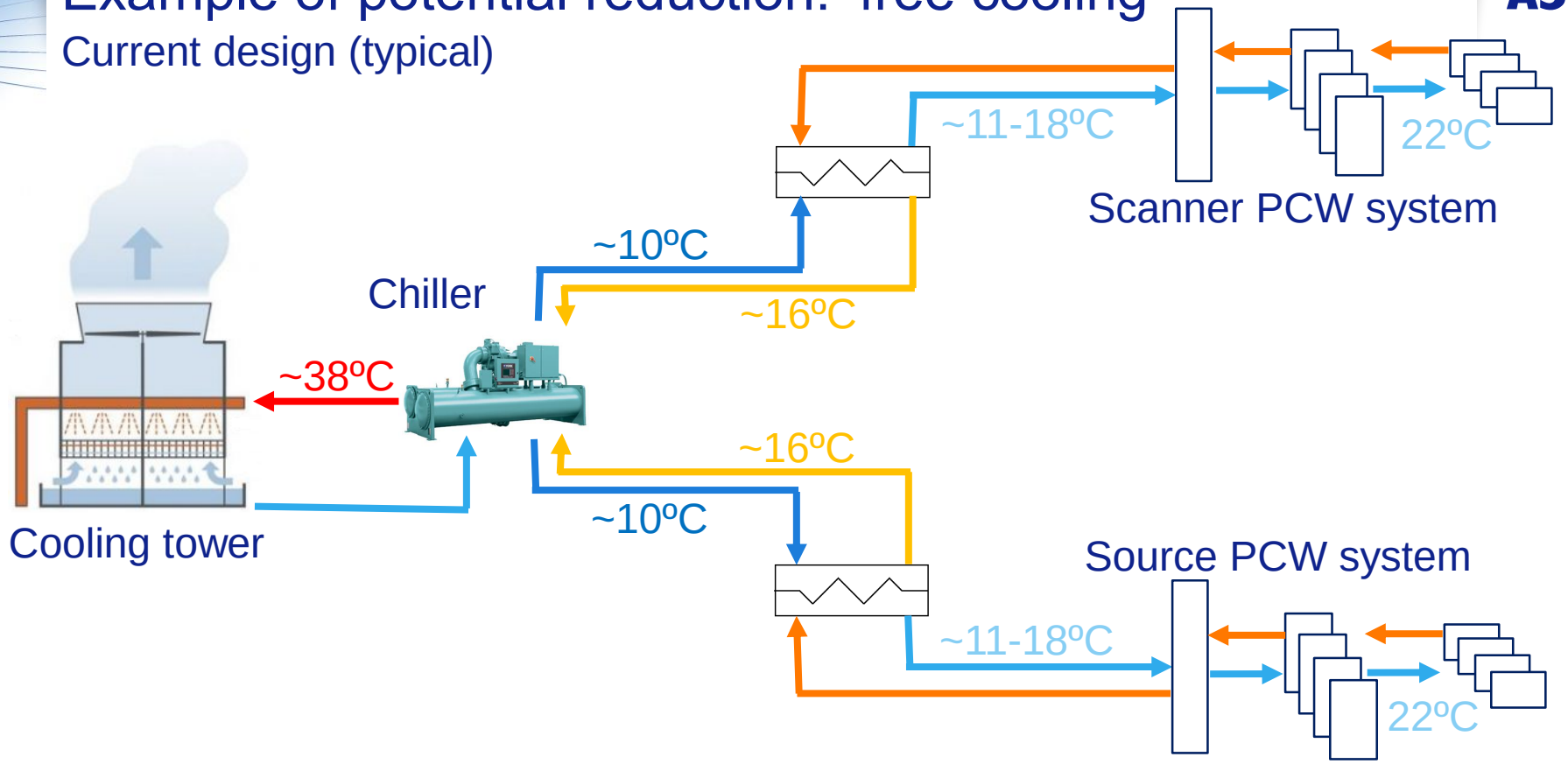
EUV facility usage – examples of potential savings

Total equivalent energy consumption and potential savings



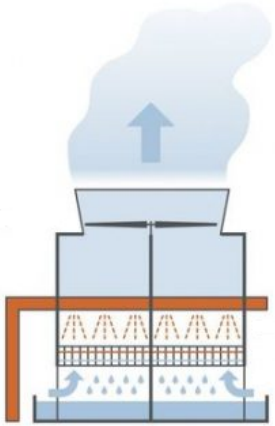
Example of potential reduction: ‘free cooling’

Current design (typical)



Example of potential reduction: ‘free cooling’

Adding “free” cooling



Cooling tower

~38ºC

Chiller

~10ºC

~16ºC

~11-18ºC

22ºC

Scanner PCW system

~16ºC

~10ºC

~11-18ºC

22ºC

Source PCW system (cold)

~30ºC

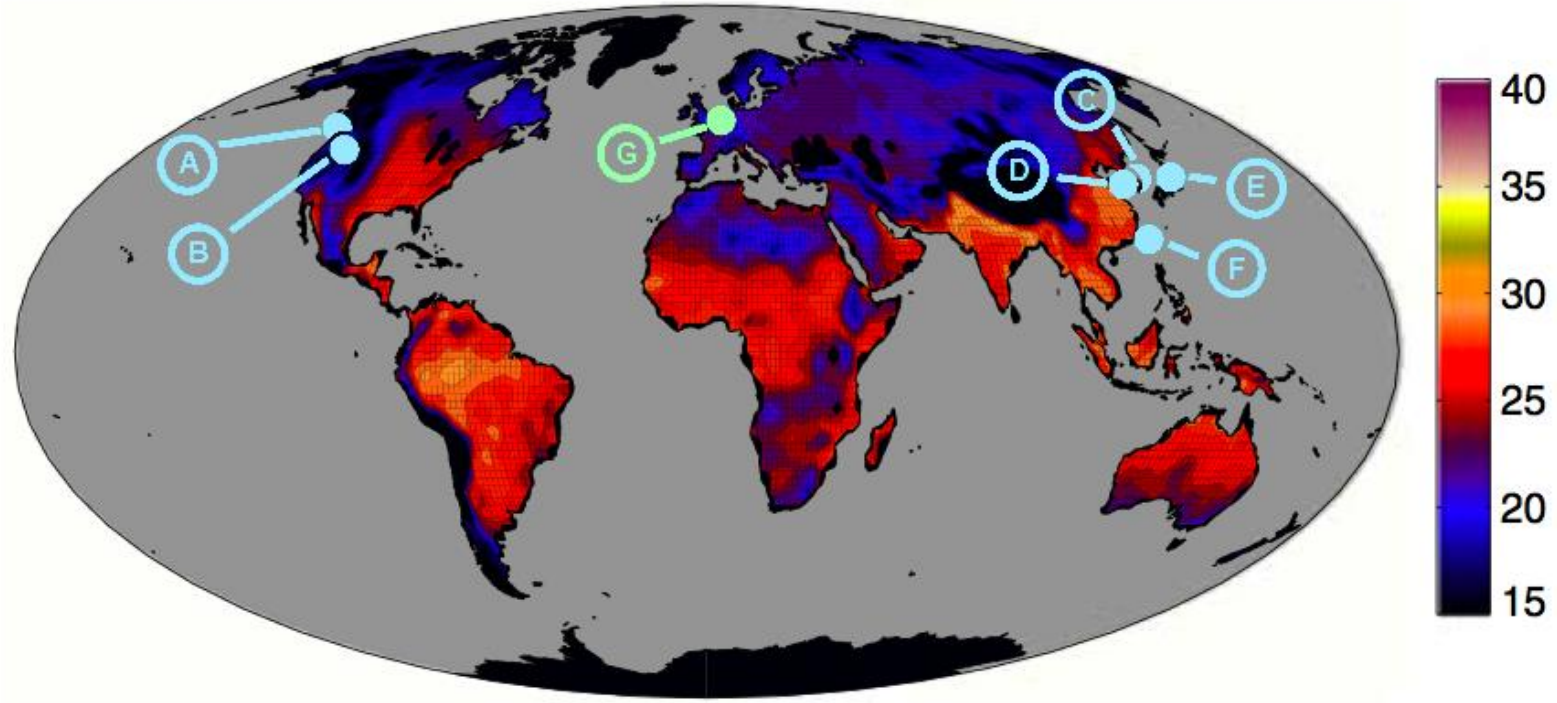
~32ºC

35ºC

Source? / PreVac? / Ecab?
‘Hot’ PCW system

Example of potential reduction: ‘free cooling’

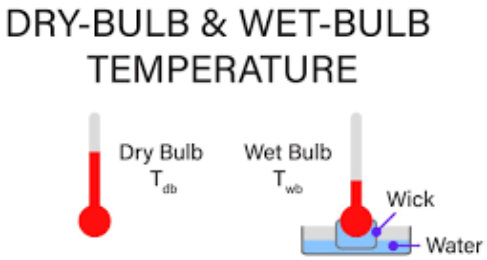
NXE Fab Sites wet bulb temperatures worldwide (°C)

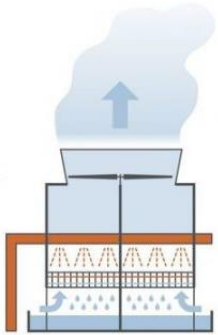


http://www.city-data.com/forum/weather/1391165-highest-wet-bulb-temperatures-around-world.html

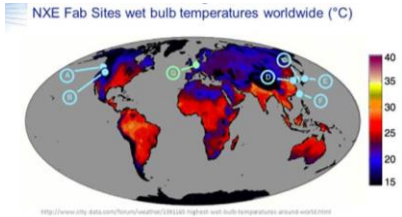
Free cooling – Temperature level diagram

Basic level for ‘free’ (non-refrigerated) cooling: Wet Bulb temperature





‘Ground level’ dictated by weather/climate: $T_{wet\ bulb} = f(T,RH)$



Need to look at ‘Wet Bulb’ statistics!

Wet Bulb temperature statistics, from ASHRAE data

Worst case NXE locations show similar conditions

Location A (Korea)

Evaporation WB/MCDB					
0.4%		1%		2%	
WB	MCDB	WB	MCDB	WB	MCDB
27.8	30.0	26.9	29.6	26.2	28.8

Location B (Taiwan)

Evaporation WB/MCDB					
0.4%		1%		2%	
WB	MCDB	WB	MCDB	WB	MCDB
28.9	32.0	28.3	31.5	27.9	31.3

Location C (Taiwan)

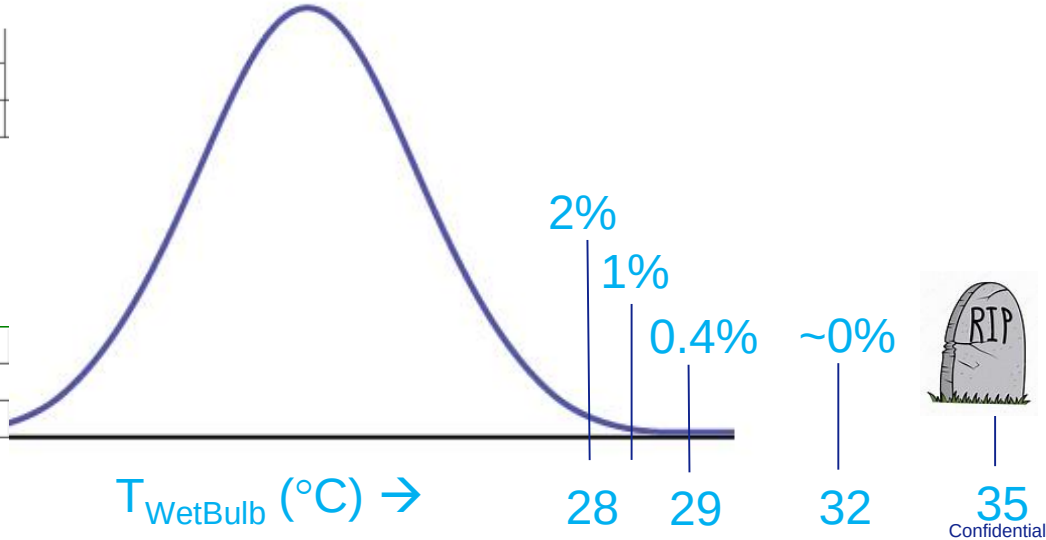
Evaporation WB/MCDB					
0.4%		1%		2%	
WB	MCDB	WB	MCDB	WB	MCDB
28.2	31.7	27.9	31.4	27.5	31.2

Typical yearly statistics (worst case):

< 28ºC for 98% of time

< 29ºC for 99.6% of time

< ~32ºC 100% of time (~20 yr horizon)



Wet Bulb temperature statistics, from ASHRAE data

Worst case NXE locations show similar conditions

Location A (Korea)

	Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature							
	Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DB	-13.8	34.0	2.5	1.4	-15.6	35.0	-17.0	35.8	-18.4	36.7	-20.2	37.7
WB	-14.8	27.3	2.3	1.7	-16.5	28.5	-17.8	29.5	-19.1	30.5	-20.8	31.7

Location B (Taiwan)

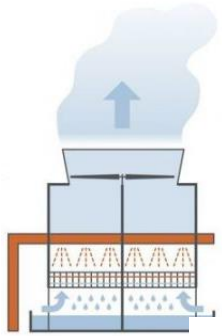
	Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature							
	Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WB	5.4	30.0	1.6	0.9	4.3	30.7	3.3	31.2	2.4	31.8	1.2	32.4

Location C (Taiwan)

	Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature							
	Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DB	9.1	34.8	1.3	0.8	8.2	35.4	7.4	35.8	6.7	36.3	5.7	36.9
WB	6.3	28.8	1.4	0.8	5.3	29.4	4.5	29.9	3.7	30.4	2.7	31.0

Free cooling – Temperature level diagram

Several margins needed on top of 'Wet Bulb' temperature



Indirect users

Cabinet water = $T_{wet\ bulb}$ + 8°C

$\Delta T_{PCW\ heat\ exchanger}$ (2-4°C)

Direct users

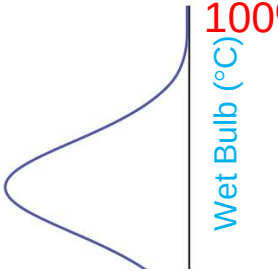
Customer PCW = $T_{wet\ bulb}$ + 5°C

$\Delta T_{PCW\ heat\ exchanger}$ (2-4°C)

Cool tower return = $T_{wet\ bulb}$ + 3°C

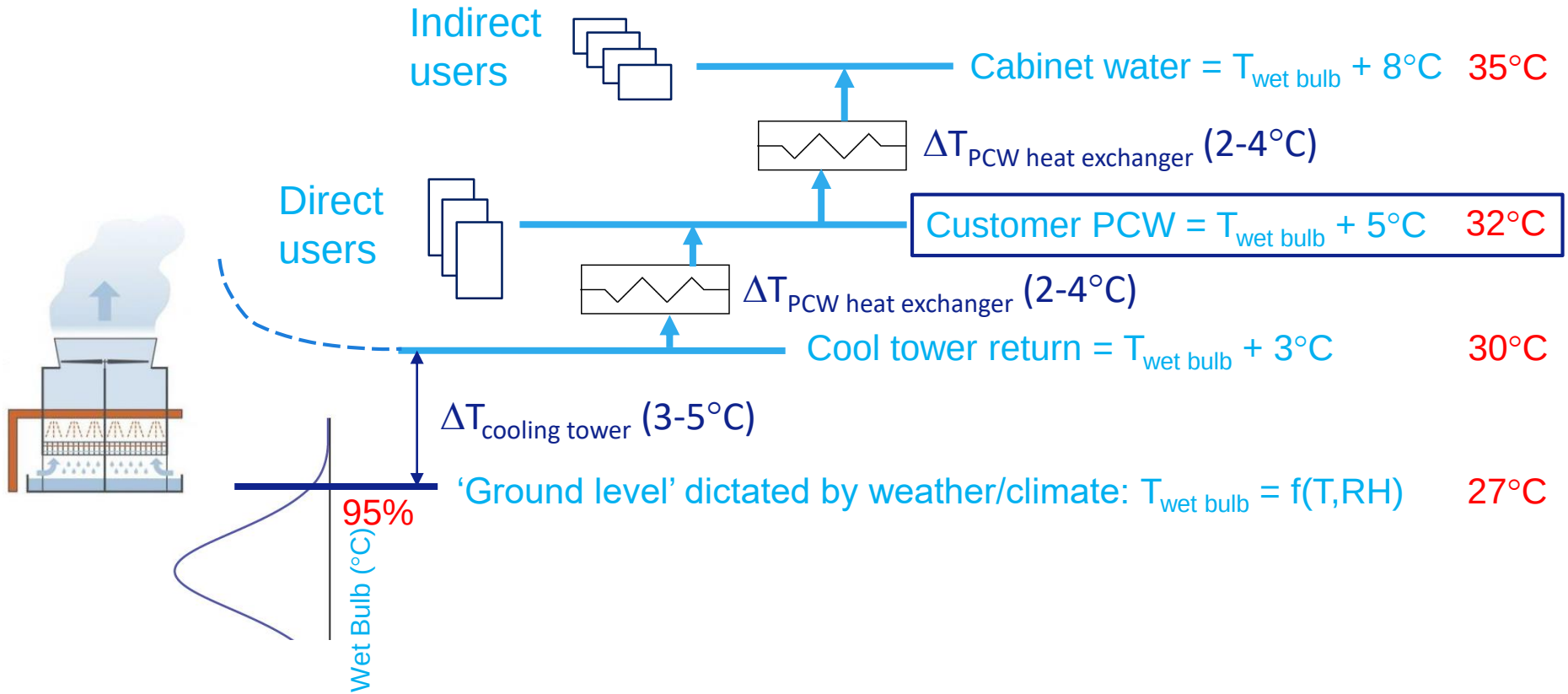
$\Delta T_{cooling\ tower}$ (3-5°C)

'Ground level' dictated by weather/climate: $T_{wet\ bulb}$ = f(T,RH) 32°C



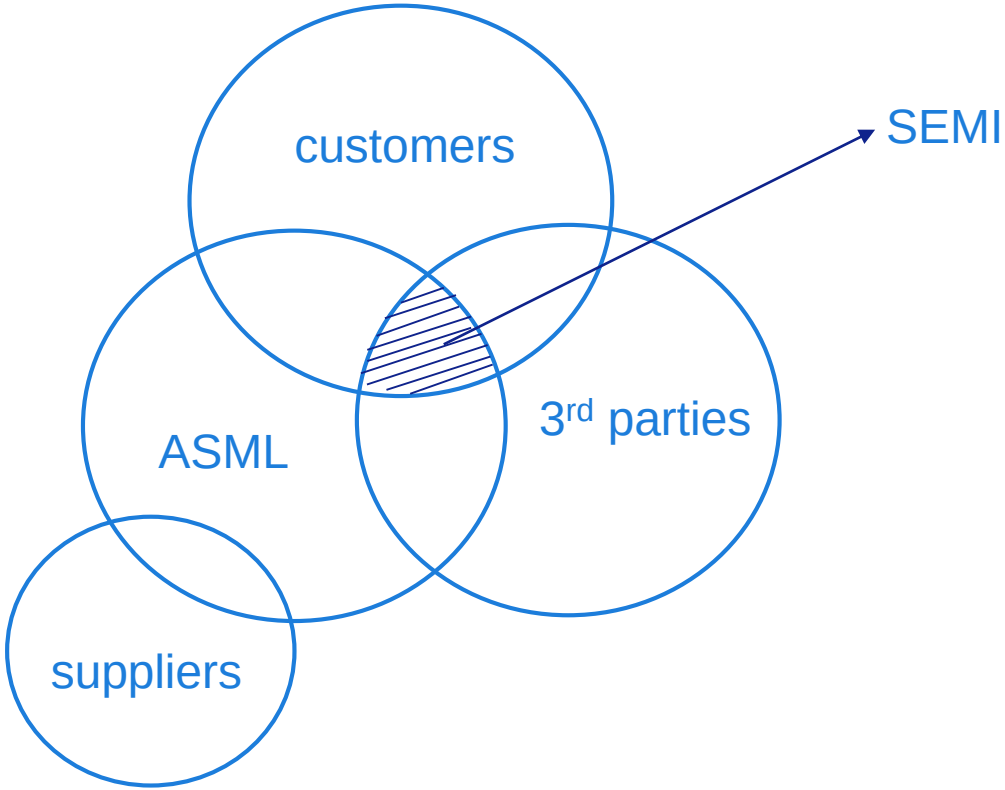
Temperature level diagram

ASML baseline: 32°C PCW, indirect users on 35°C



‘Free cooling’ requires multiple parties to cooperate

SEMI organization is at ‘crossroads’, taking care of standardization



SEMI S23 task force

Towards a new standard (version)

- SEMI: Semiconductor Industry Association, tasked with standardization

- S23: standard related to energy use, with guidelines on how to report tool energy consumption. Current version dates from December 2016.
  - Facility consumption is also included, via ‘Energy Conversion Factors’ (ECF)

- I joined S23 task force ~1.5 year ago, proposing two additions:
  - Guidelines to implement ‘warm cooling water ‘HTPCW’ (for energy saving)
  - Additional ECF’s for hydrogen and natural gas (for reporting accuracy)

SEMI S23 task force

Towards a new standard (version)

- SEMI (and Task Force) membership is voluntary;
  - some members are from industrial parties
  - others are (sometimes retired) consultants, ‘ZZP-ers’
- Meeting structure: teleconferences, and twice a year face-to-face
- ‘Challenging’ process

The organizational challenge…

The organizational challenge…

- Broad support to put sustainability on the agenda:
  - Top-down: quantitative targets, supported by increasing customer pressure
  - Bottom up: many people see the need for climate action!

- Challenge for middle management levels:
  - Energy saving not required from a (traditional) functional perspective: easy victim in case priority calls needs to be made
  - Financial business case often weak in (traditional) accounting

- Trend towards sustainability is clear and ASML acts on it via:
  - Continuous alignment with leading customers on best way to approach it;
  - Customer/supplier teams that guide product and fab infra improvements
  - Sr management commitment to middle management. Company targets

The Balance

Energy consumption per transistor in a chip reduces drastically
Enabled by ASML technology

Fast and small chips enable energy saving technologies

- Advanced teleconferencing as alternative for flying
- Computing power to optimize device performance (e.g. ‘Toon’)
- Autonomous driving

Increase in # transistors per chip (Moore’s law) and # chips outweighs energy reduction per transistor

- Data centers
- Bitcoin mining
- …

To push the scaler further to the left, together with customers and suppliers, ASML invests in reducing energy waste and improving energy efficiency of its products.