



# High NA introduction: a sustainable choice?

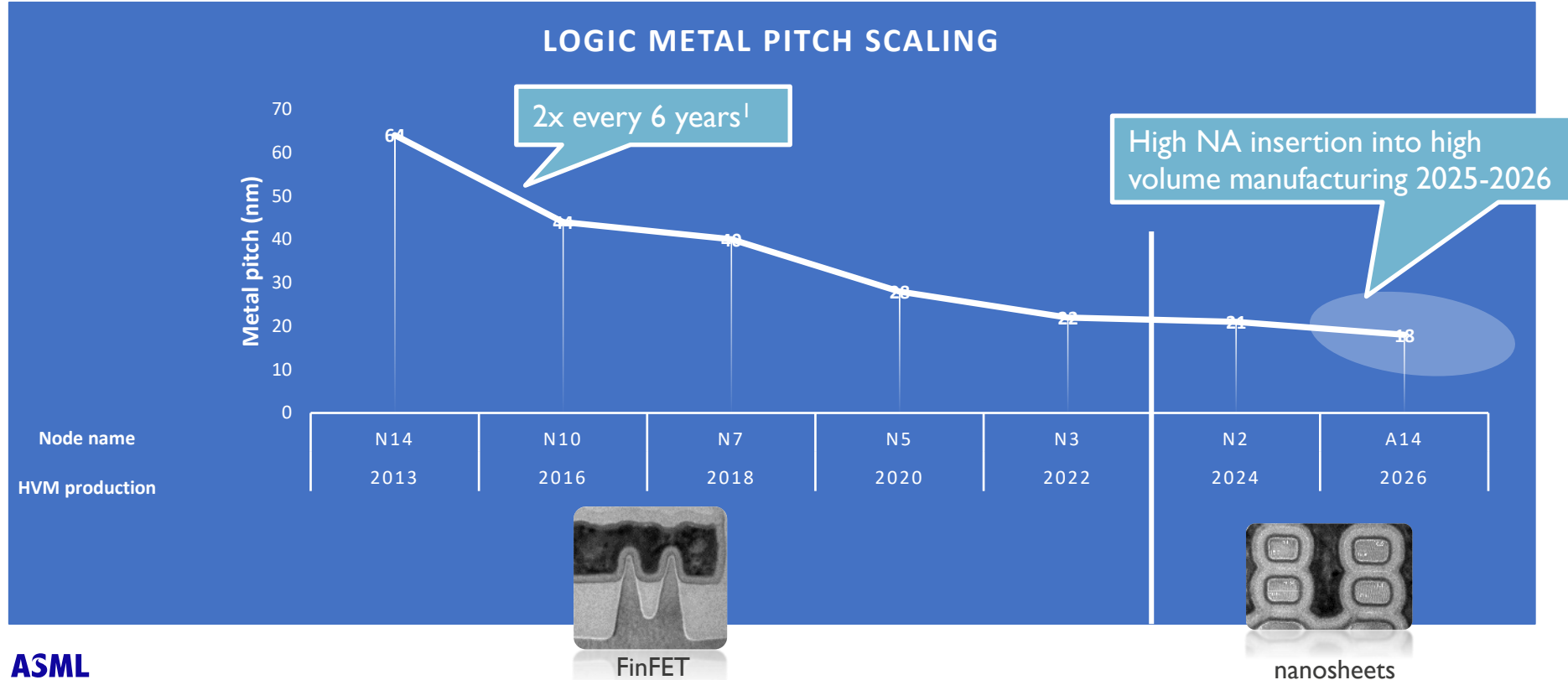
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ASML: Carlo Luijten, Diederik de Bruin, Martijn Gram, Theo Thijssen

# Outline

- Introduction
  - Density scaling and lithography resolution trends
  - Emissions associated with IC production
- High NA lithography
  - Introduction to scanner principles
  - Consequences for power consumption
- Process emission comparison
  - Example case: low NA LELE vs. high NA LE
  - Dependence on scanner productivity
- Conclusions

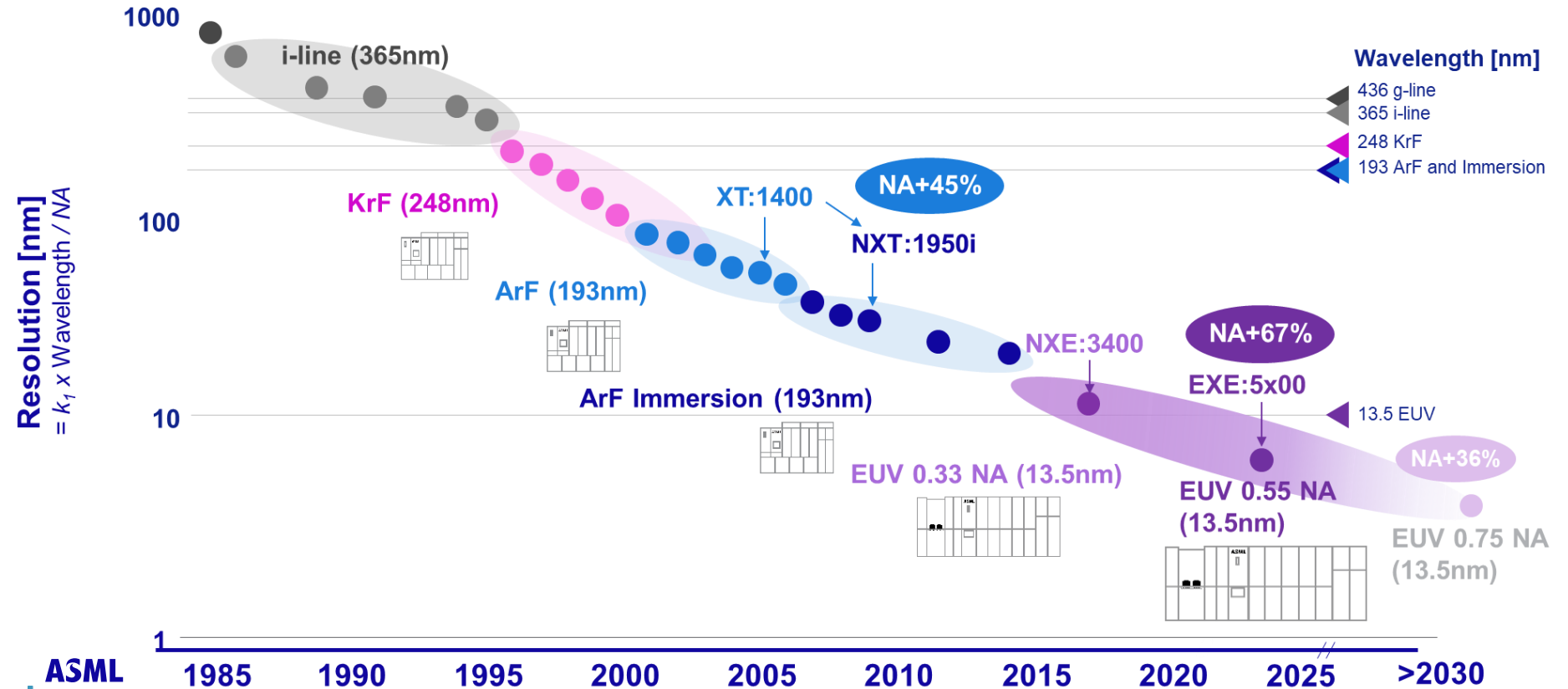
# Density scaling: result of pitch scaling and device scaling



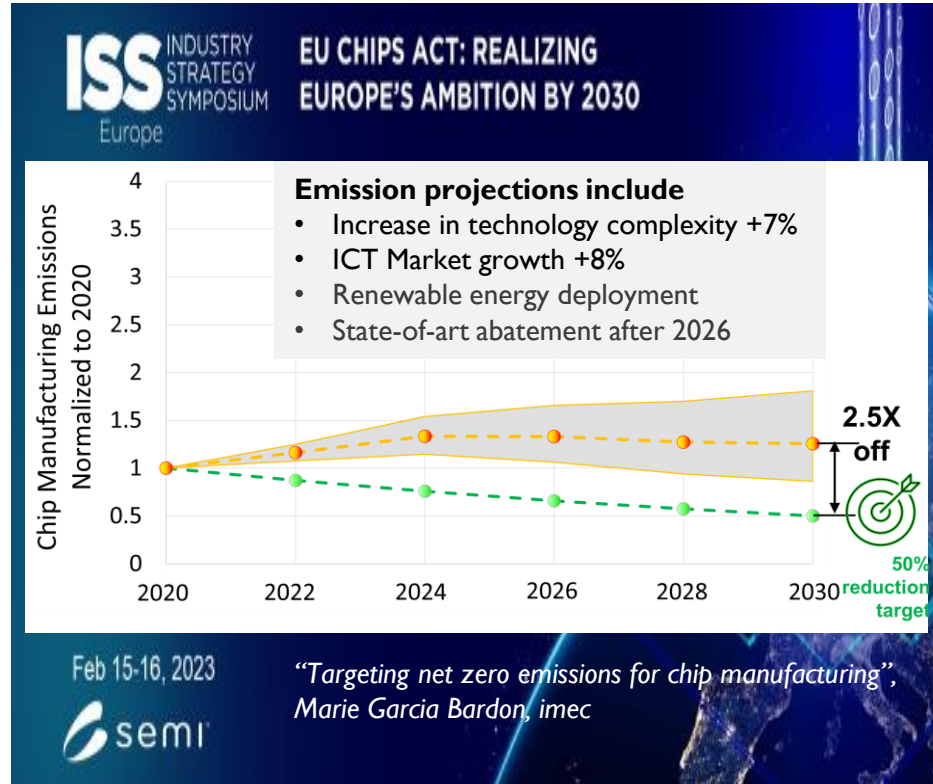
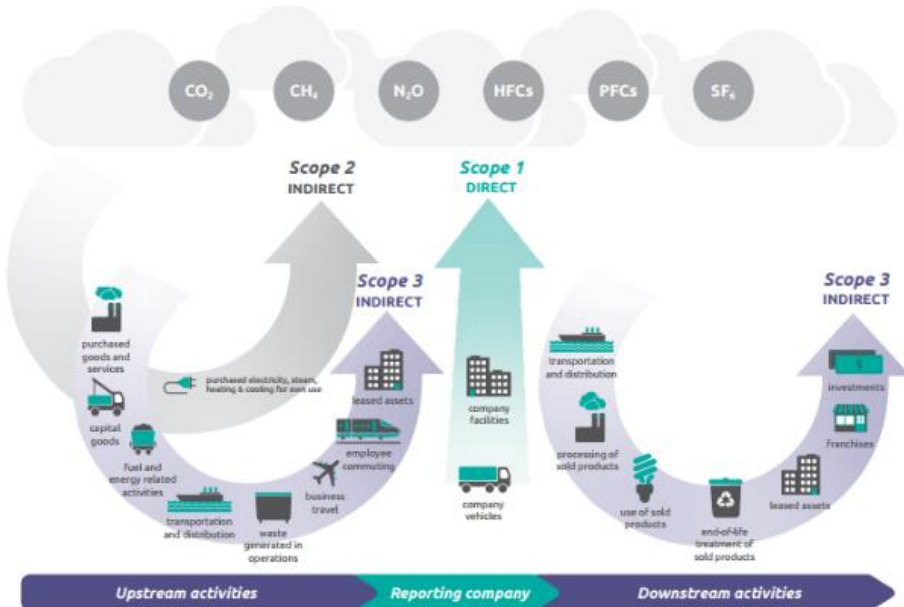
# Resolution driven by wavelength and NA

Optical resolution improves moving to higher NA values

$$CD_{highNA} \approx \frac{0.33}{0.55} CD_{lowNA}$$

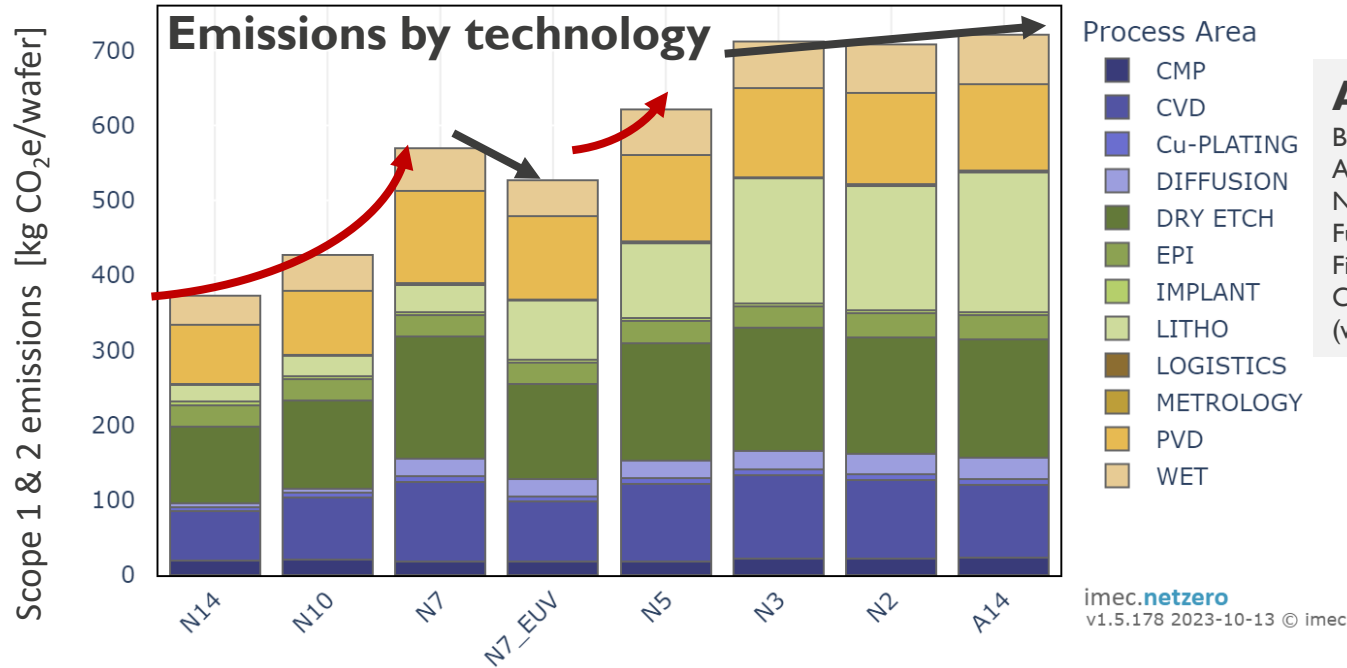


# Carbon emissions in the IC industry



# Carbon emission by logic technology node per wafer

Low NA EUV reduced emissions; rate of increase slows for advanced nodes because of device scaling



## Assumptions:

By wafer (no yield included)  
Abatement: tier 2C with combustion  
No UPW recycling  
Full field exposure with 10x10mm<sup>2</sup> dies size  
Fixed tool utilization – 70%  
Carbon intensity mix – 0.456 kgCO<sub>2</sub>/kWh  
(weighted avg of fab locations)

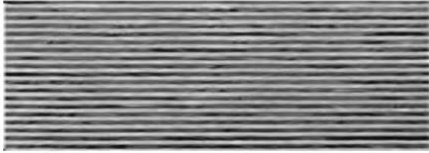
EUV introduction reduces overall emissions for a given node by eliminating process steps

# Introduction to high NA lithography

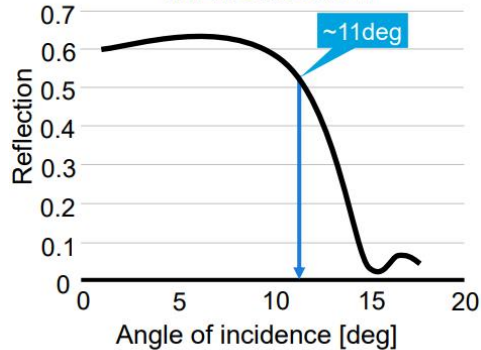
# High NA EUV: scanner design features relative to low NA

EUV mirrors limit angles

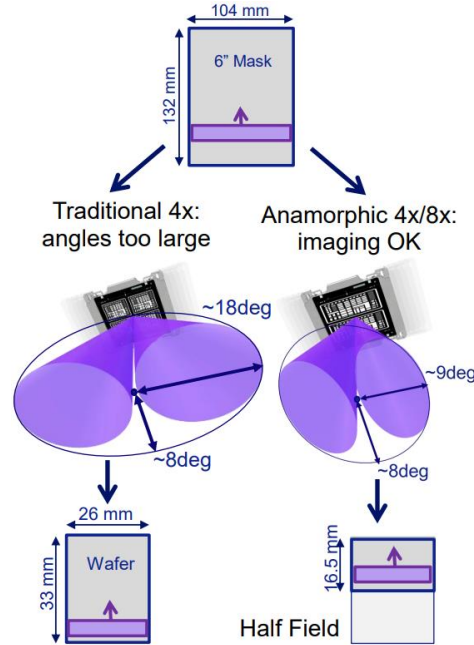
Mask MoSi Multilayer



ML reflection



Anamorphic imaging satisfies angles, but limits reticle field in y



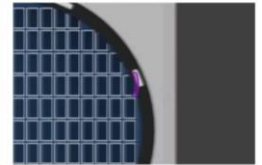
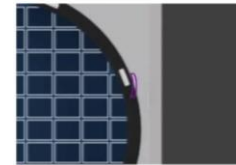
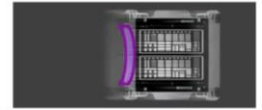
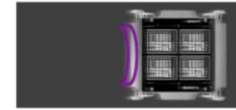
Increased stage speeds maintains wafer throughput



Acceleration of mask stage ~4x



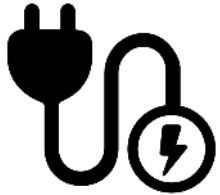
Acceleration of wafer stage ~2x



# Energy comparison of NXE3800 and EXE5200

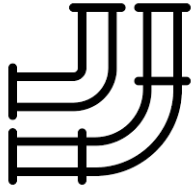
Common EUV source, increased stage power consumption due to anamorphic lens

direct power

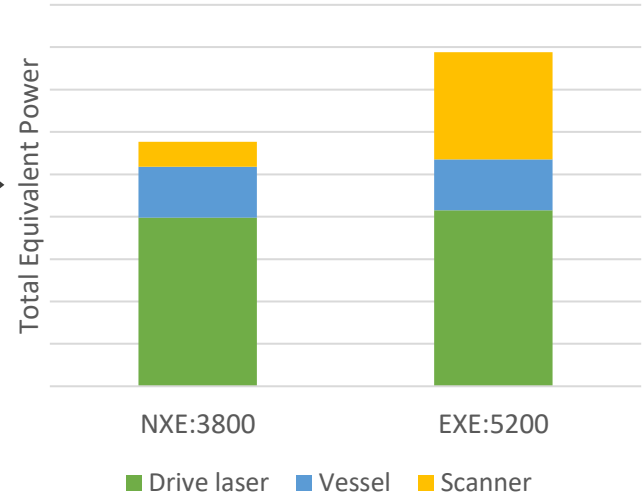


SEMI S23 energy  
conversion factors

indirect power  
(gases, cooling)



NXE:3800 vs EXE:5200  
energy consumption



# Simple example of high NA introduction

# Litho-Etch Litho-Etch (LELE) vs. Litho-Etch

Low NA  
LELE



Lithography1  
Coating and patterning



Etch1 and strip films  
Pattern transferred into oxide



Lithography2  
Coating and patterning



Etch2 and strip oxide  
Full pattern transferred to TiN

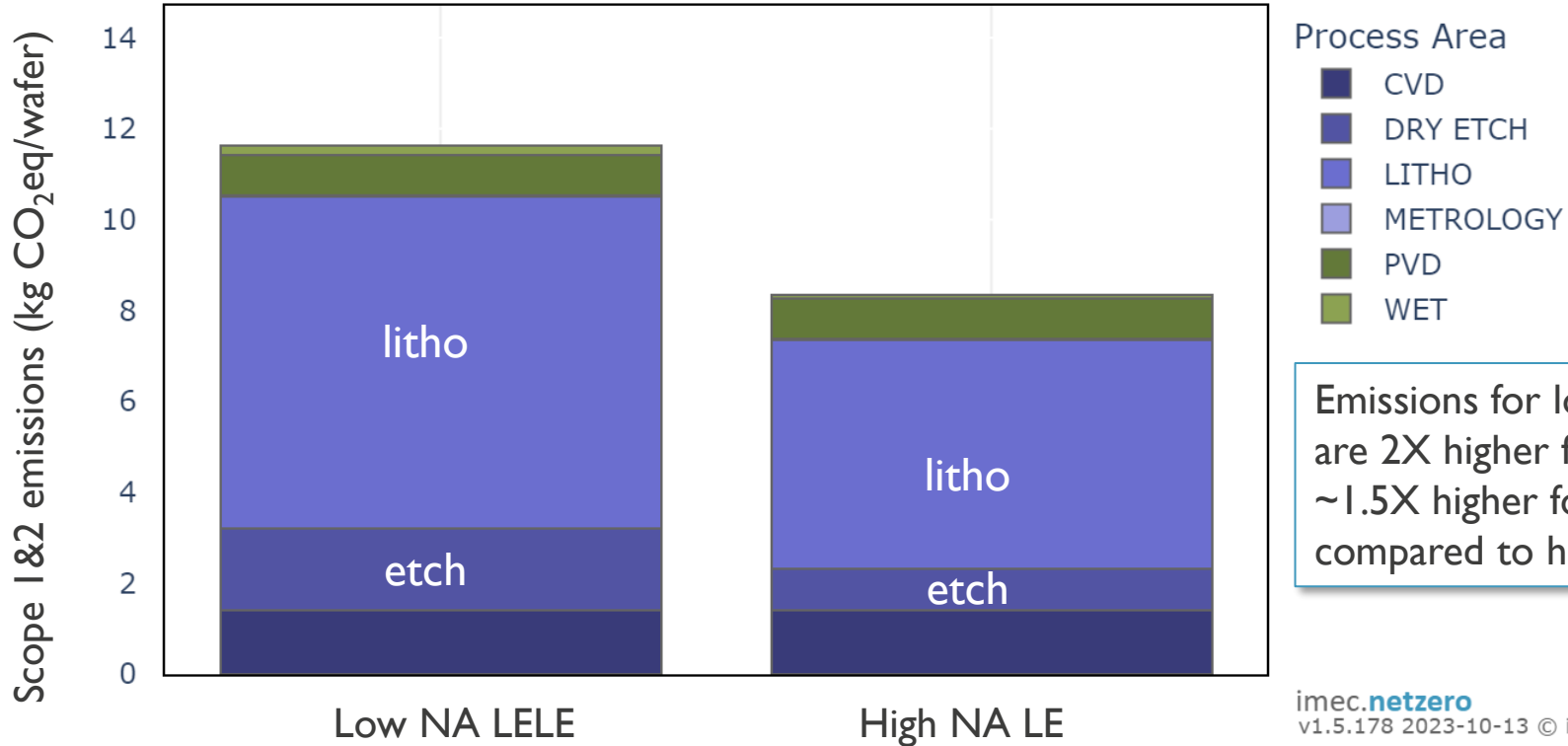
High NA  
LE



Main emission drivers are  
lithography and etch;  
anticipate lower emissions in  
high NA LE scenario

# High NA insertion impact on emissions

Nominal 220 wph throughput for both low NA NXE:3800 and high NA EXE:5200

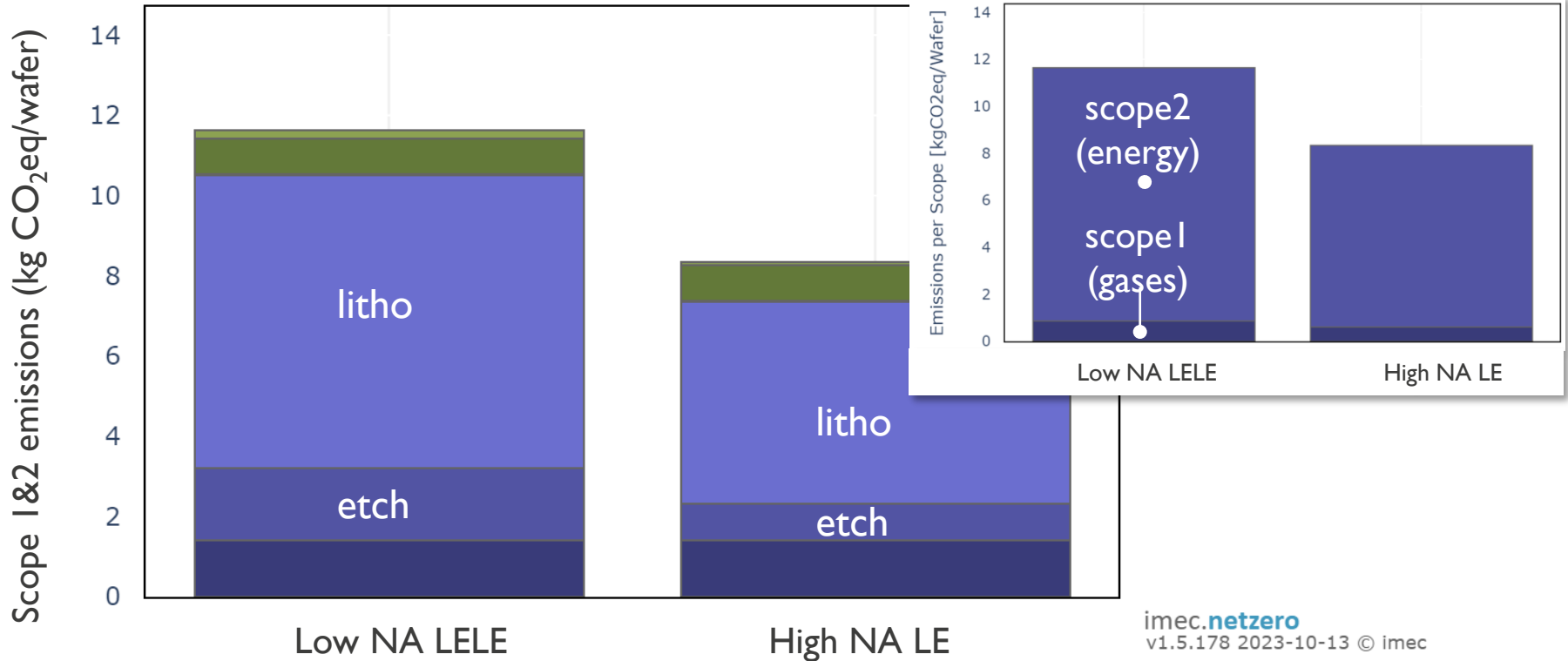


Emissions for low NA LELE are 2X higher for etch and ~1.5X higher for lithography compared to high NA LE

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# High NA insertion impact on emissions

Dominated by reduction in Scope 2 scanner and etch emissions (energy)



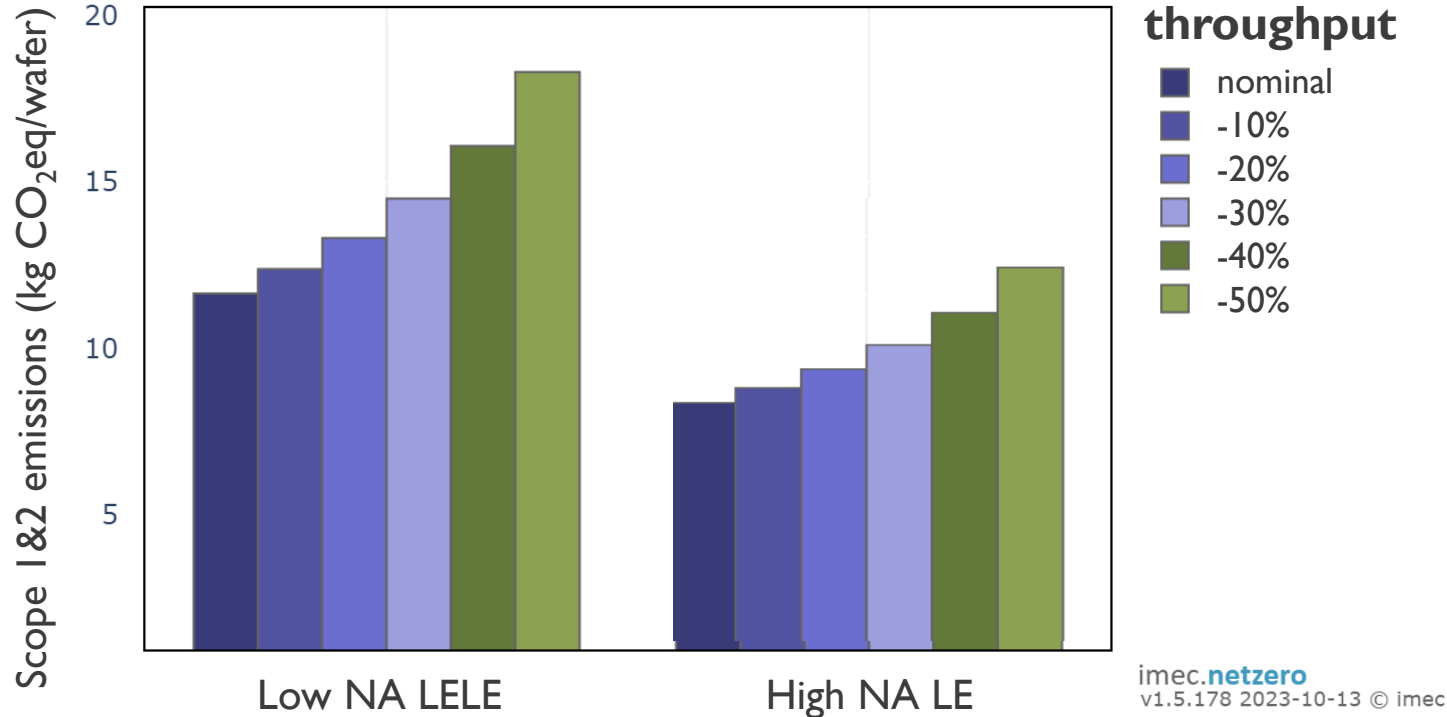
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What if scanner throughput  
changes?

# Emissions as a function of scanner throughput

Sensitivity to scanner throughput: nominal (220wph @30mJ/cm<sup>2</sup>) to -50%



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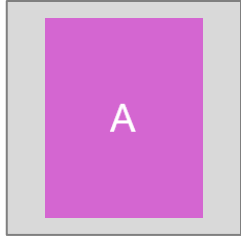
# Reticle: low NA and high NA

Influence of high NA field size on throughput (TPT)

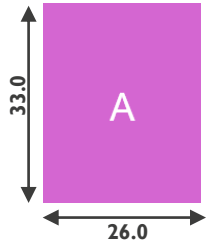
Reticle

Wafer

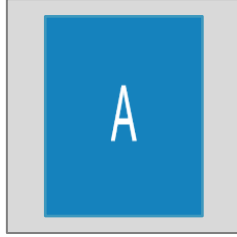
Low NA



full field



High NA



high-NA  
half field

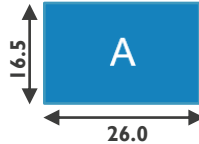
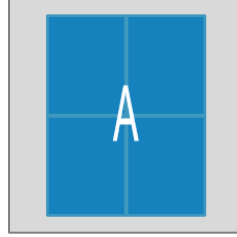


image size = half field



2 high NA fields = 1 low NA field

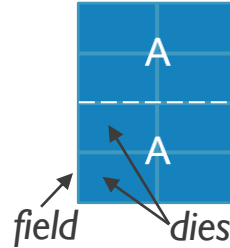
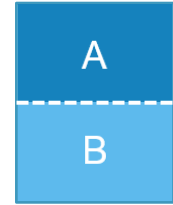
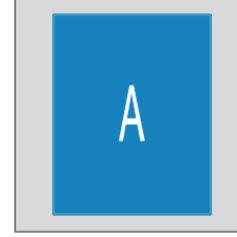


image size > half field



EXE:5200 TPT @30mJ/cm<sup>2</sup> (wph)

220

135\*

% of maximum

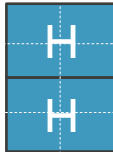
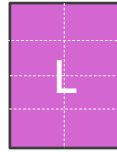
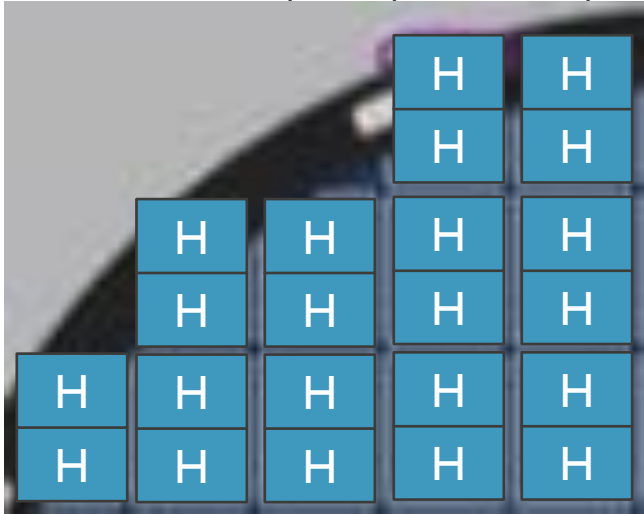
100% (nominal)

-40%

# Exposing a wafer – simplified and slowed

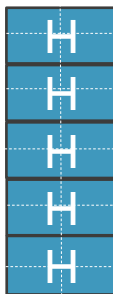
On wafer, low NA exposures must be matched by high NA exposures

Low NA exposure fields on a wafer



## Even rows

2 high NA fields for each full field low NA



## Odd rows

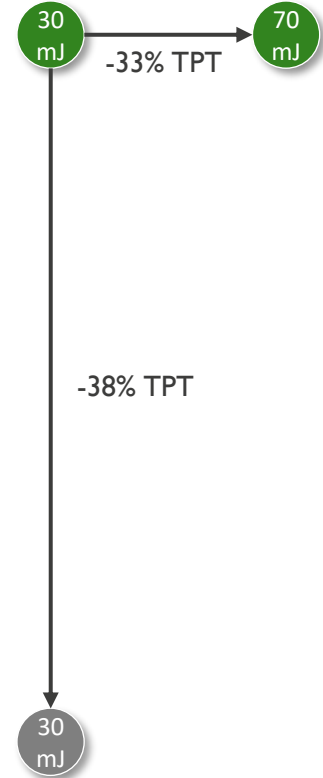
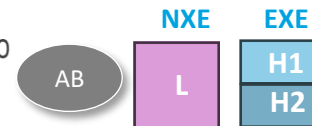
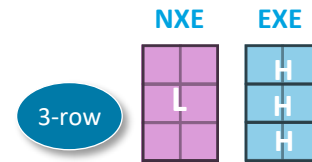
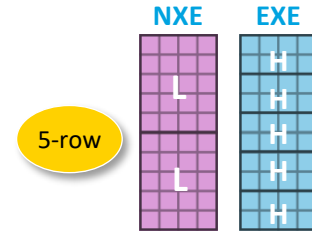
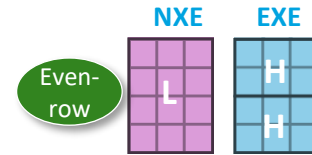
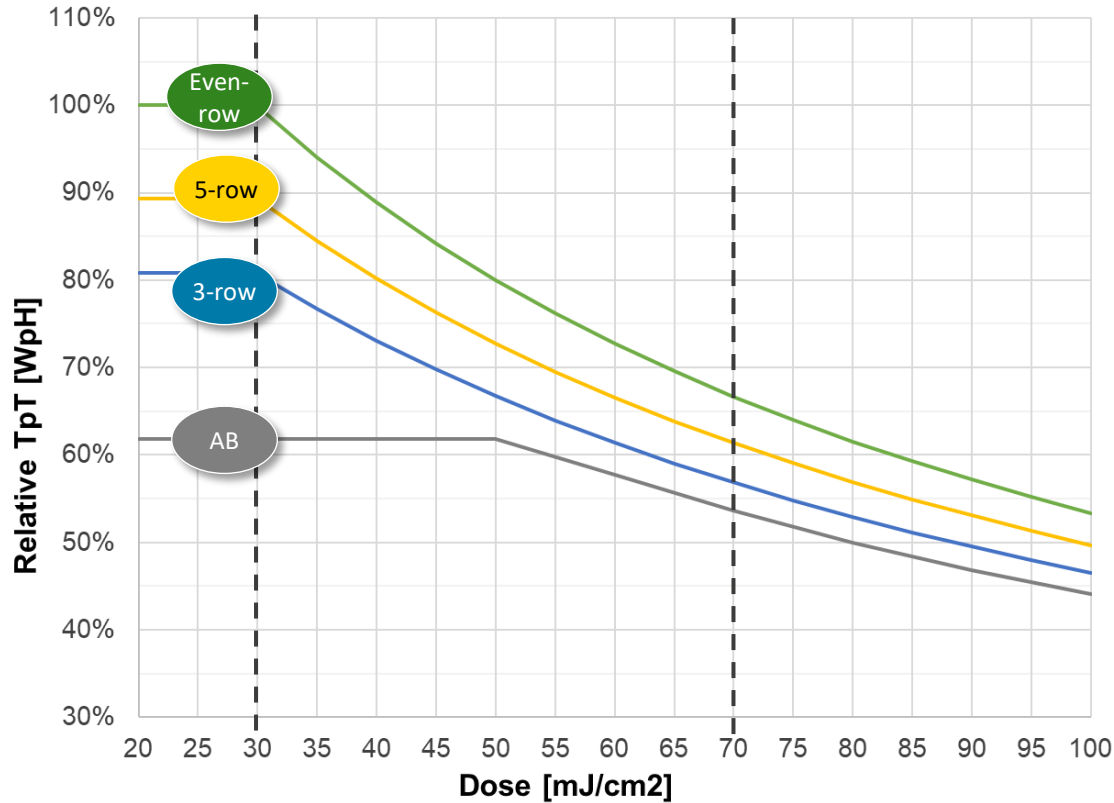
More high NA fields needed



## Larger than $\frac{1}{2}$ low NA fields

2 high NA masks for each full field low NA

# High NA throughput (TPT) vs. dose and layout

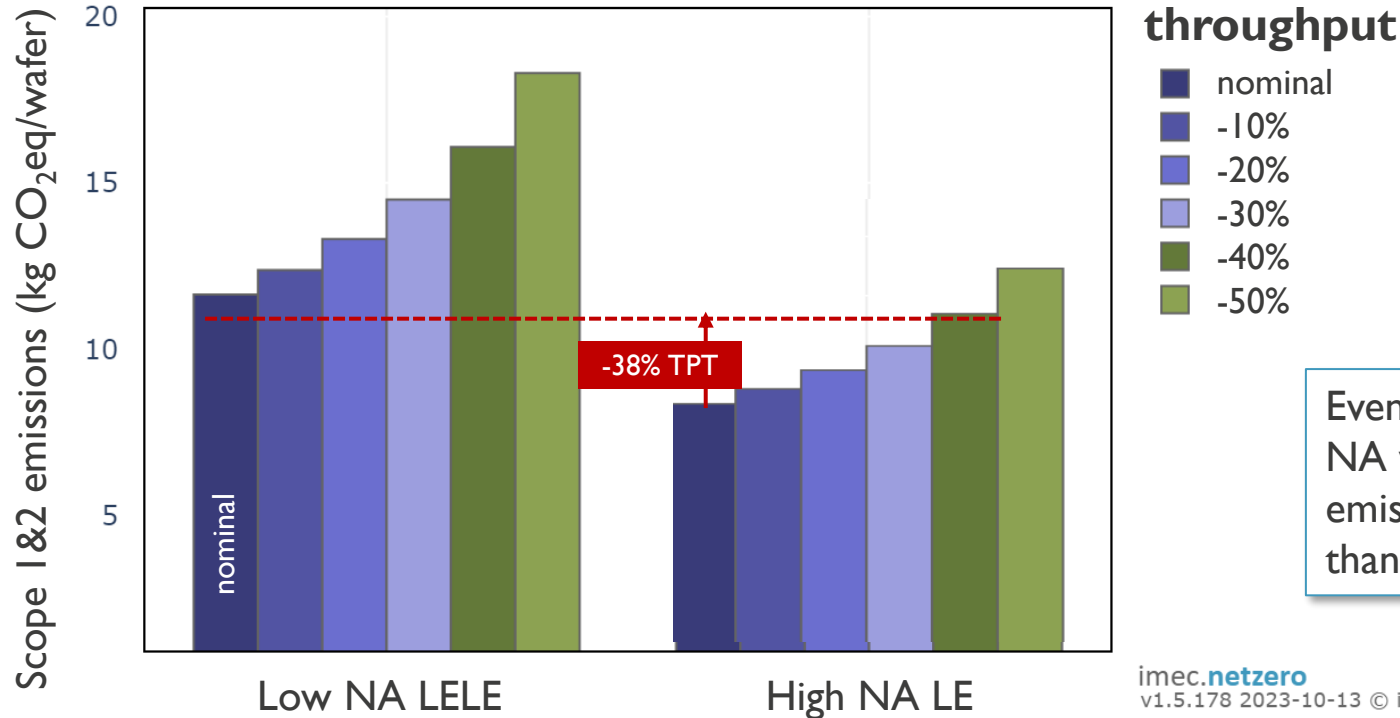




Is introducing high NA  
lithography a sustainable choice?

# Emissions as a function of scanner throughput

Sensitivity to scanner throughput: nominal 220wph @30mJ/cm<sup>2</sup> to -50%



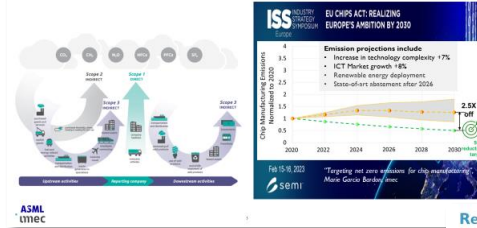
Even when using high NA with two reticles, emissions are lower than low NA nominal

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# Conclusions

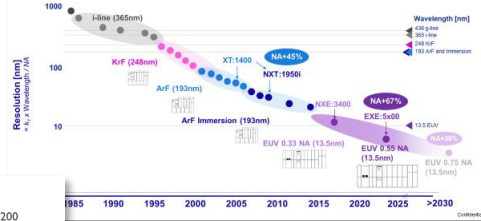
- Available technology both in tools and process design must be deployed for maximum efficiency to approach 'net zero' targets
- High NA introduction enables continued CD scaling while limiting complex multi-patterning
- Total process emissions using high NA will be lower compared to multi-patterning low NA
  - Despite higher power consumption of scanner
- To further increase energy efficiency of high NA:
  - Keep field size below 26mm x 16.5mm (half field)
  - If larger than half field, use even number of die rows
  - Minimize exposure dose where possible, capitalizing on better contrast of high NA

## Carbon emissions in the IC industry



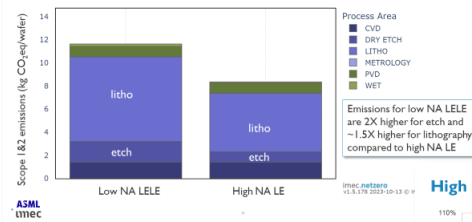
## Resolution driven by wavelength and NA

Optical resolution improves moving to higher NA values



## High NA insertion impact on emissions

Calculated at 220 wph throughput for both low NA NXE:3800 and high NA EXE:5200



## High NA throughput (TPT) vs. dose and layout

