Cost Analysis of Lithography Options for Panel-Level Fan-out Packaging

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Introduction

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Prior to joining SavanSys, Amy held positions in business development at TOK America and in engineering at Nokia Japan. Amy has a degree in chemistry and spent one year on a Fulbright grant before beginning work at Nokia.

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Agenda

- **Introduction**
  - Activity Based Cost Modeling
  - Lithography Options
- **Baseline Case**
- **Sensitivities**
- **Summary**

Activity Based Modeling Details

Cost Components of each Activity

- The time required to complete the activity
- The amount of labor dedicated to the activity
- The cost of material required to perform that activity – both consumable and permanent material
- Any tooling cost
- The depreciation cost of the equipment required to perform the activity
- The yield loss associated with the activity

RDL Process Flow

- **Analysis focuses on RDL creation**
- **Many types of fan-out exist**
  - Doesn't matter which is modeled here, since they all need an RDL
- **Assume an OSAT-style, copper-polymer RDL**
  - Some steps will only exist for some of the lithographic options

Summary of Process Steps

Dielectric Layer 1	Apply dielectric (may be photoimagable or non-photoimagable)
	Pattern dielectric (may include expose and develop steps)
Metal Layer	Sputter barrier and seed layer
	Apply photoresist
	Pattern photoresist
	Plate up metal layer
	Strip resist, etch barrier and seed layer
Dielectric Layer 2	Apply dielectric (may be photoimagable or non-photoimagable)
	Pattern dielectric (may include expose and develop steps)

Lithography Options

Global Assumptions

- Assume all four lithography solutions have equipment that can support a panel
- Assume all can meet design requirements for the comparisons shown
  - *Not all lithographic methods can achieve the same resolution*
- Capex for new equipment is not considered
  - *Make the comparison as apples-to-apples as possible*

Lithography Options

Aligner

- Mature option, relies on photoimagable dielectric that is patterned, then developed
- Mask is same size as wafer, so entire wafer is exposed at once
- Method modeled is proximity aligner (mask does not make contact with wafer)
- Cost notes: Inexpensive equipment, fast throughput, lower yield than other options (since entire wafer exposed at once), multiple masks are needed for one lithographic step
  - *To handle some of the common misalignment that occurs (e.g. from warpage) earlier in the process.*

Stepper

- Incumbent process for RDLs built on wafers
- Relies on photoimagable dielectric that is patterned, then developed
- Smaller pattern is projected, or stepped, across the wafer (instead of whole wafer exposed in pattern at one time)
  - *Typically can achieve finer l/s than an aligner*
- Cost notes: Expensive equipment, throughput is slower, one mask assumed for one lithographic step

Lithography Options

Laser Direct Imaging (LDI)

- Maskless process – Laser beam directly patterns the dielectric
- Still relies on photoimagable dielectric that is patterned, then developed
- Cost notes: Equipment cost is higher than aligner but lower than a stepper, throughput is highly dependent on design

Laser Ablation

- Maskless process – Laser directly ablates (removes) the dielectric
- Dielectric does not have to be photoimagable, develop step is skipped
- Cost notes: Equipment cost is higher than aligner but lower than a stepper, throughput is highly dependent on design

BASELINE COMPARISON

Baseline Comparison

➢ Design notes

- 6x6mm package, 600x600mm panel
- Dielectric material is assumed to be a film

➢ Baseline Assumption Notes

- Each technology has nuances that can't be reflected in a simple comparison
  - *Goal of comparison is to understand the major cost drivers*
- Aggressive assumptions are used for this baseline case (such as setting the yield and throughput of the laser-based processes equal to a stepper)

	Stepper	Aligner	LDI	Laser Ablation
Equipment Cost ($)	x	0.375x	0.5x	0.5x
Throughput (WPH)	x	1.33x	1x	1x
Yield Hit	x	2x	1x	1x
Mask Cost* ($)	x	4x	-	-
Dielectric Material Cost ($)	x	1x	1x	0.7x
Develop Step Cost ($)	x	1x	1x	-

*Takes into account cost of mask(s) and number of masks required for a single patterning step

Baseline Comparison Results

➢ Results notes

- Assume lithography option shown is used for both dielectric layers
  - *Metal layer is assumed to use a stepper*
- All results are shown relative to a stepper
- Results refer to the total cost of a single RDL (dielectric, metal, dielectric)

Technology	Labor	Material	Capital	Yield Hit	Total
Stepper	1.00	1.00	1.00	1.00	**1.00**
Aligner	0.96	1.02	0.79	1.46	**0.90**
LDI	1.00	0.99	0.83	0.97	**0.91**
Laser Ablation	0.95	0.80	0.77	0.94	**0.79**

Baseline Comparison Results

Technology	Labor	Material	Capital	Yield Hit	Total
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Labor Costs

- Fairly equal – Dependent on throughput and number of steps
  - *Aligner less expensive because of fast throughput*
  - *Laser ablation less expensive because of fewer steps (no develop step)*

Material Costs

- Highest for aligner because of the assumption that multiple masks are needed for a single lithography step (to correct for common alignment errors)
- Lowest for laser ablation
  - *No masks, dielectric does not have to be photoimagable, no developer cost*

Baseline Comparison Results

Technology	Labor	Material	Capital	Yield Hit	Total
Stepper	1.00	1.00	1.00	1.00	**1.00**
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Capital Costs

- Highest for stepper because of equipment cost and throughput assumption
- Lower, and similar, for other three options
  - *Aligner and laser equipment each assumed to be cheaper to some degree*
  - *No capital costs associated with the develop step for the laser ablation process*

Yield Hit

- Highest hit for aligner because of assumption that the yield is lower
- Same yield assumed in stepper, LDI, and laser ablation processes
  - *However, yield accrues on top of total cost, so with the LDI and laser ablation processes being less expensive under the current assumptions, overall yield it his lower*

Baseline Comparison Results

Technology	Labor	Material	Capital	Yield Hit	Total
Stepper	1.00	1.00	1.00	1.00	**1.00**
Aligner	0.96	1.02	0.79	1.46	**0.90**
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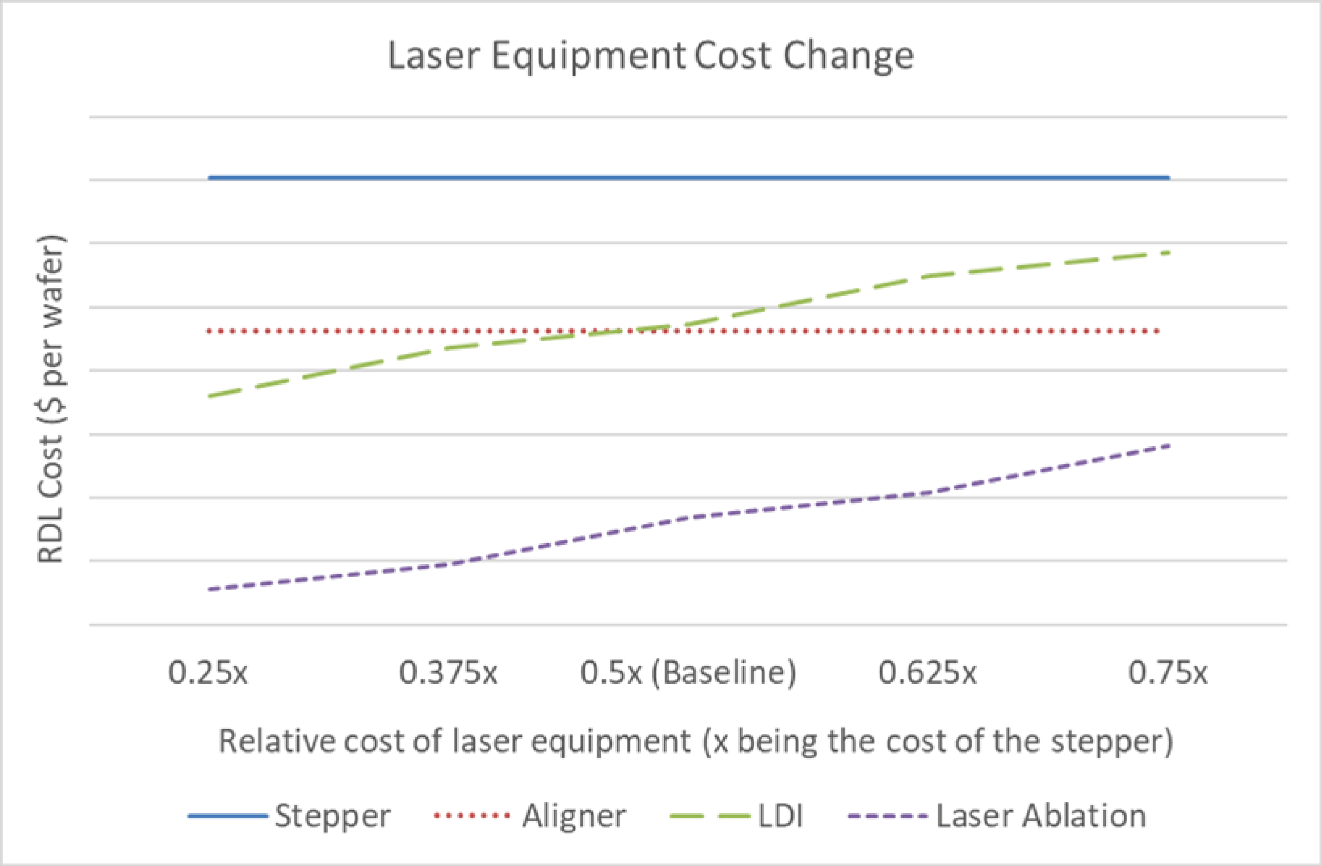
- **Key Takeaway**
  - Under the aggressive assumptions that either laser-based process can achieve the same yield and same throughput as a stepper can achieve, they are both more cost-effective than a stepper
  - If a mask aligner can meet the design requirements, it is more cost-effective than a stepper even given a reduced yield

SENSITIVITIES

Sensitivity Analysis

- **Sensitivity analysis goal**
  - Understand how costs change in reaction to a single variable
- **Focus on laser-based lithography processes**
  - Since the stepper and aligner processes are both more mature options for RDL creation
- **Test three variables**
  - Equipment cost
  - Throughput
  - Yield

Sensitivity Analysis



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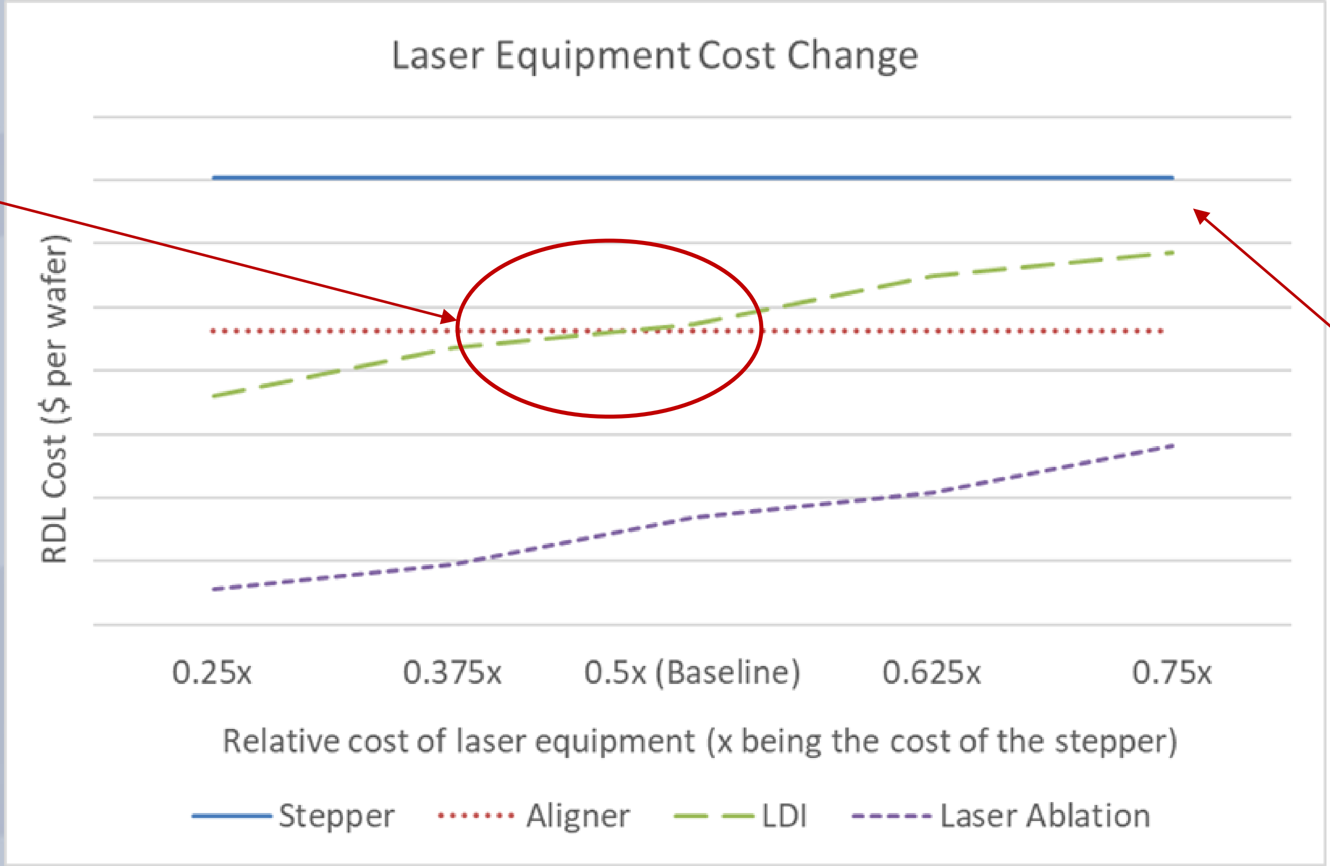
Sensitivity Analysis

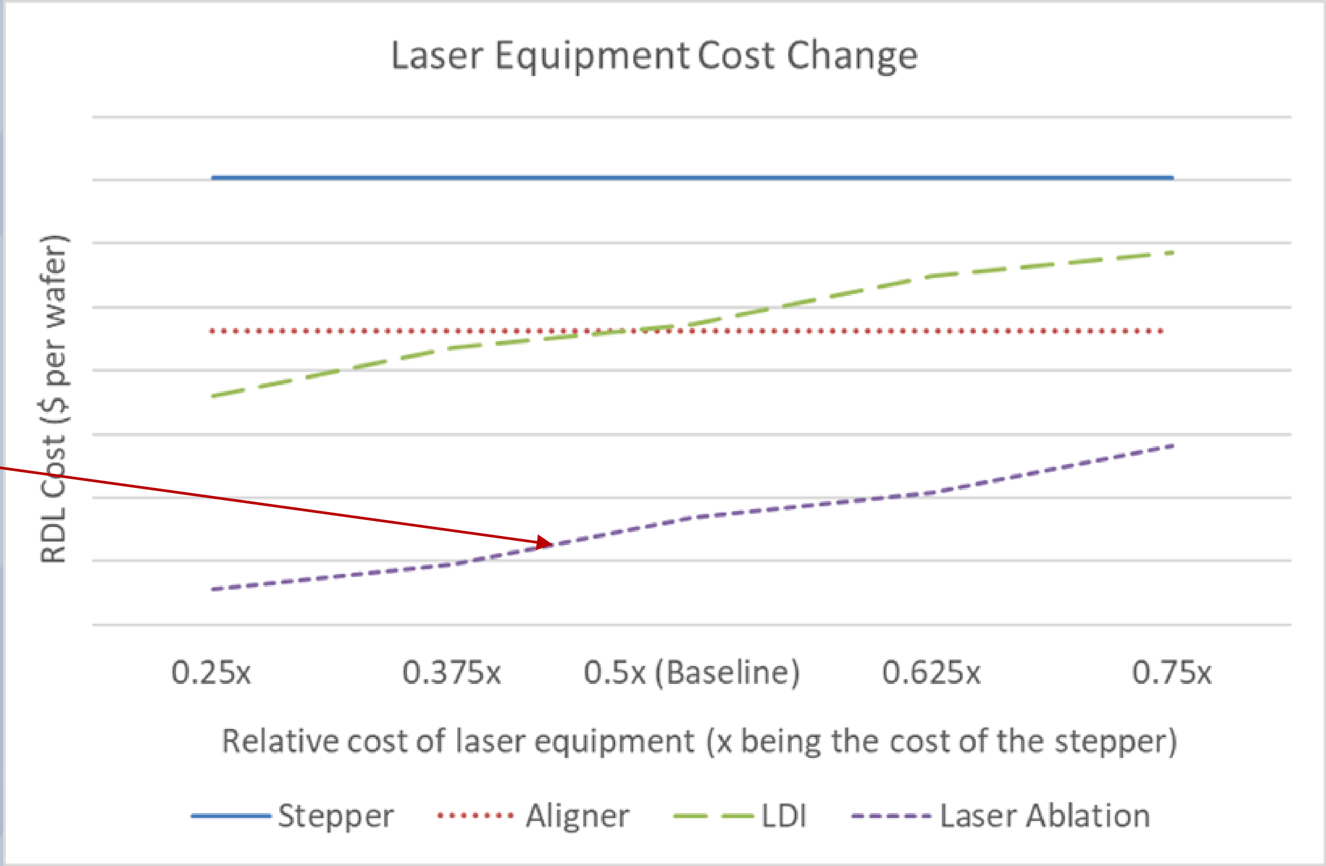
Cost of an RDL using an LDI process becomes less cost-effective than a process using an aligner with any increase in equipment cost



If LDI equipment was notably more expensive, it would no longer compete with a stepper-based process

Sensitivity Analysis

Even if the equipment was closer to the cost of a stepper (or the same as a stepper), the laser ablation process still competes with the other three lithographic solutions



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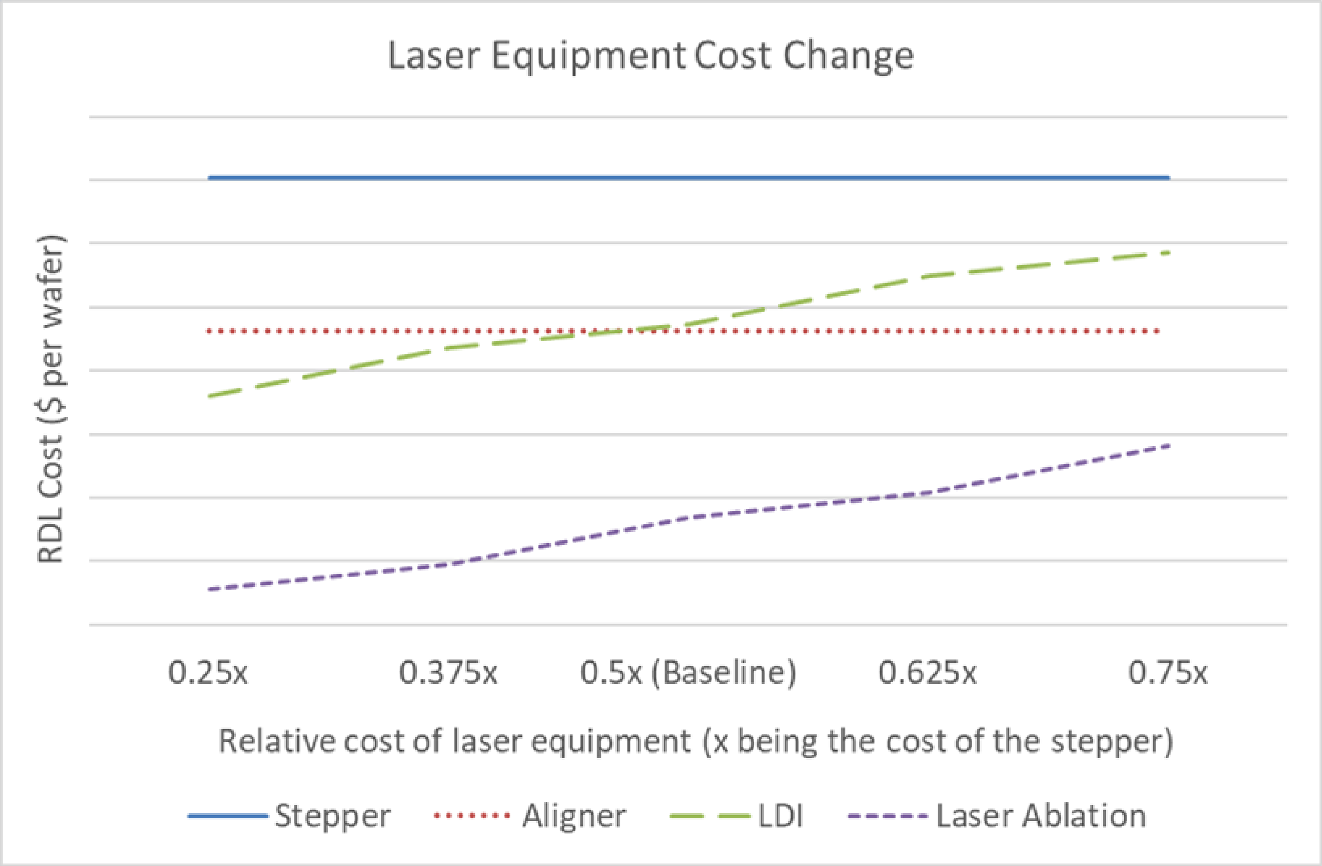
Sensitivity Analysis



Takeaway: Equipment cost is a medium cost driver

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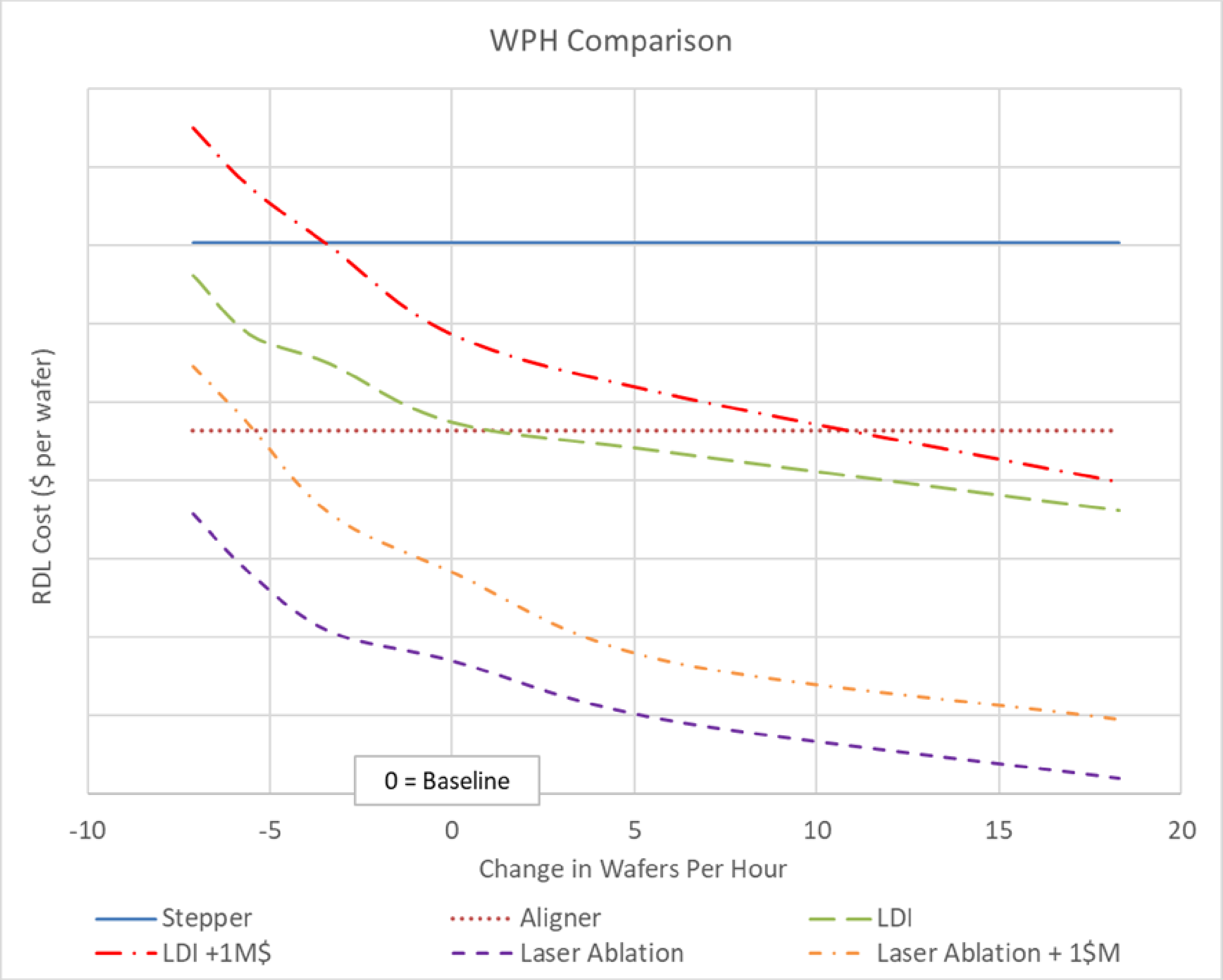
Sensitivity Analysis

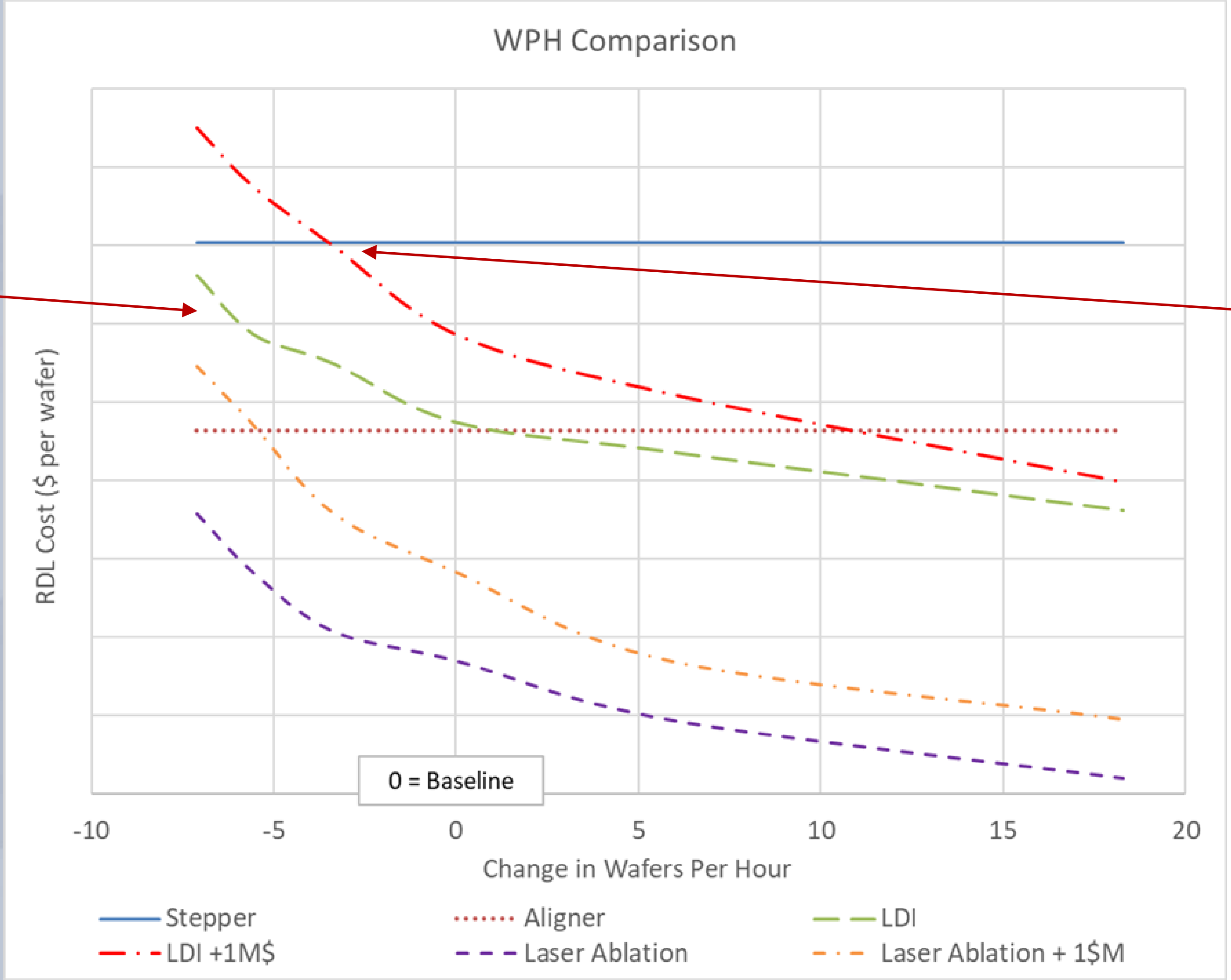


Sensitivity Analysis

Cost of an RDL using an LDI process is heavily dependent on throughput.

Under baseline assumptions, any loss in throughput means it will not compete with an aligner process.

A loss of ~8 WPH in processing would make the LDI process less cost-effective than a stepper-based process.



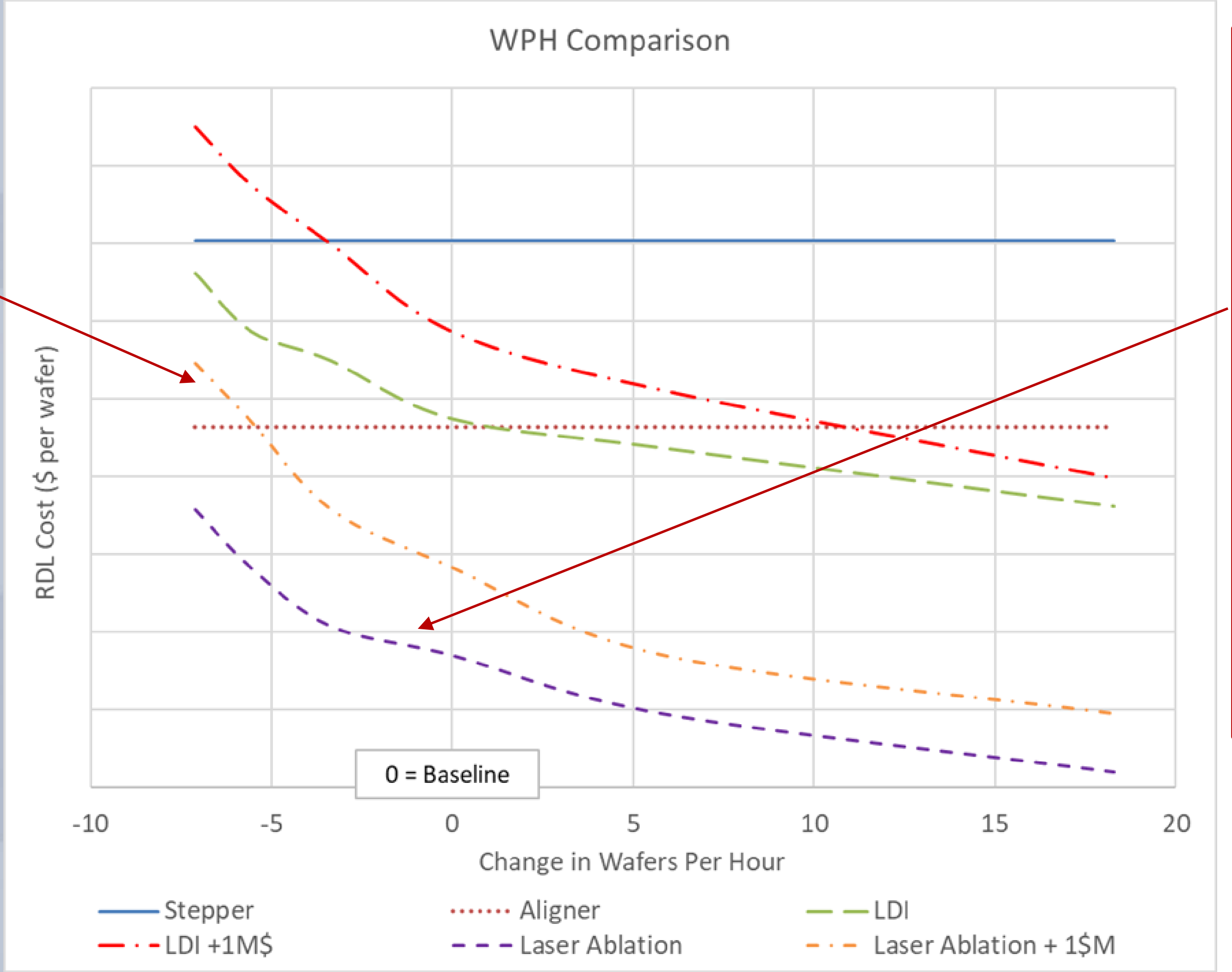
If LDI equipment was $1M more expensive and processed ~4 fewer WPH than a stepper, it would no longer compete with a stepper.

Sensitivity Analysis

Cost of an RDL using a laser ablation process is heavily dependent on throughput.

If the equipment costs $1M more than the baseline scenario, a loss of ~5 WPH would mean it is more expensive than using an aligner.

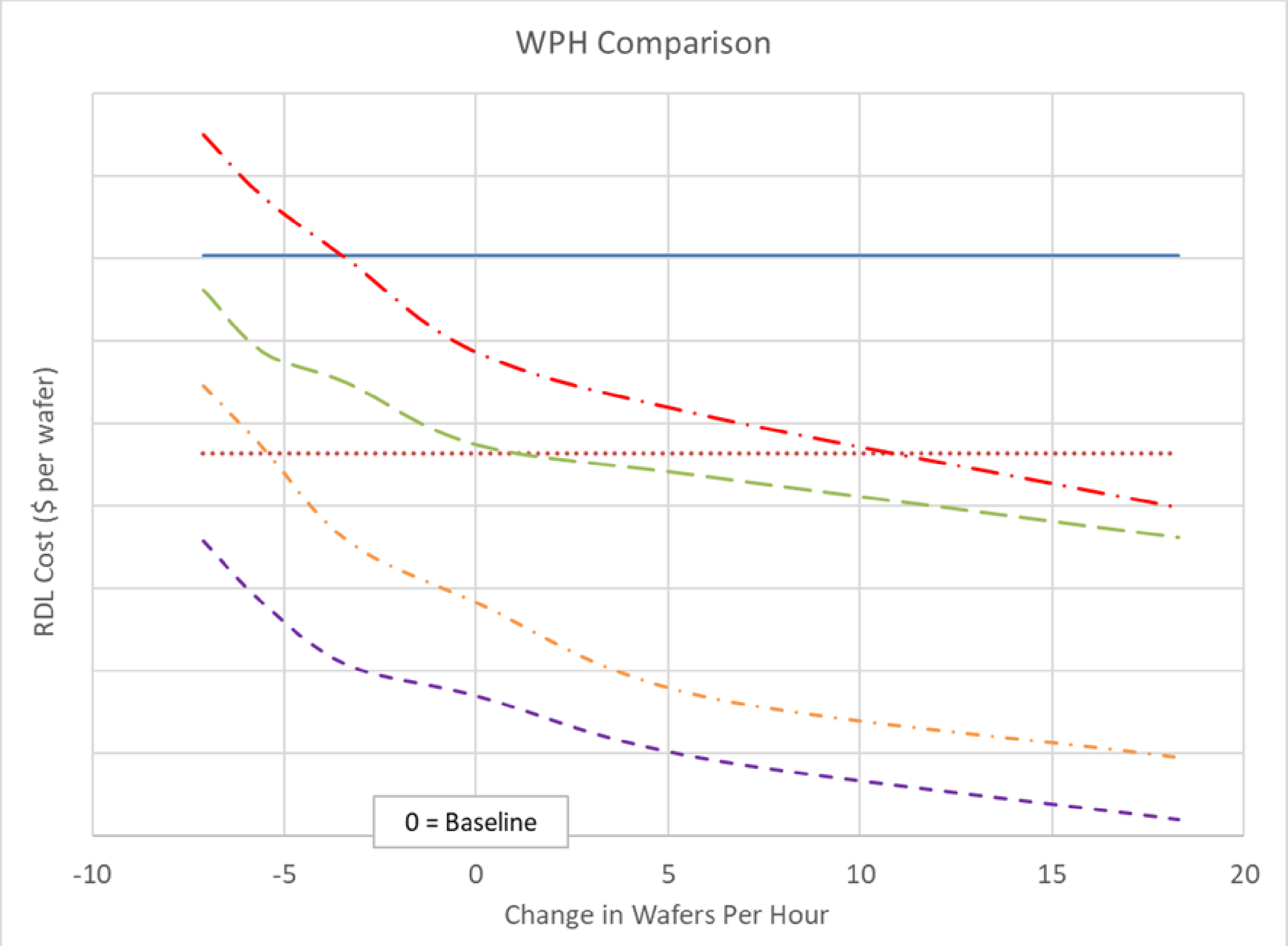
A loss of about 8 WPH would mean the laser ablation process would no longer compete with an RDL generated from a stepper.



At the baseline assumption of the equipment costing 1/2 of a stepper, the laser ablation process is still competitive with a loss of 5 wafers per hour in processing speed.

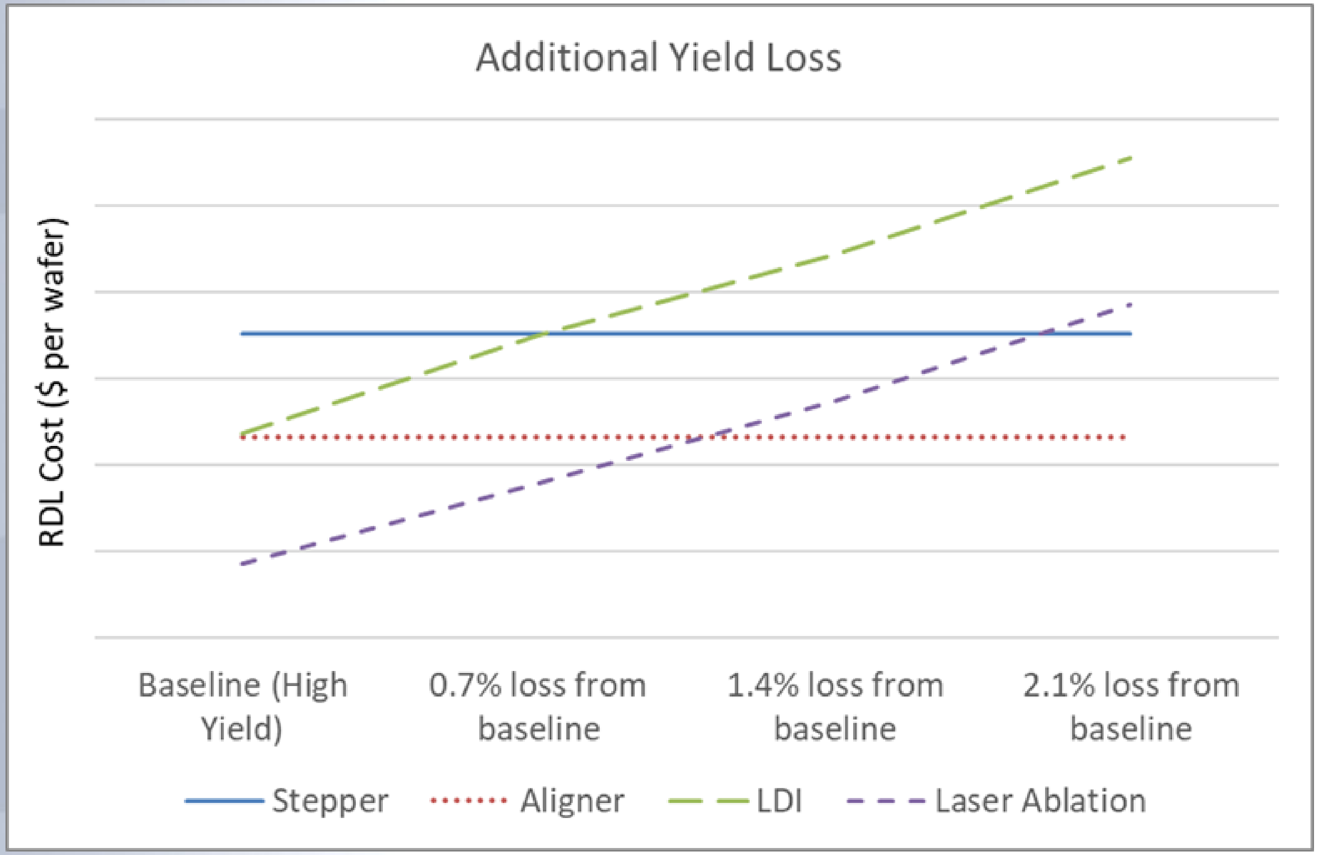
A loss of 8 WPH would make it less cost-effective than an aligner. A loss of about 11 WPH, and it would not compete with a stepper.

Sensitivity Analysis



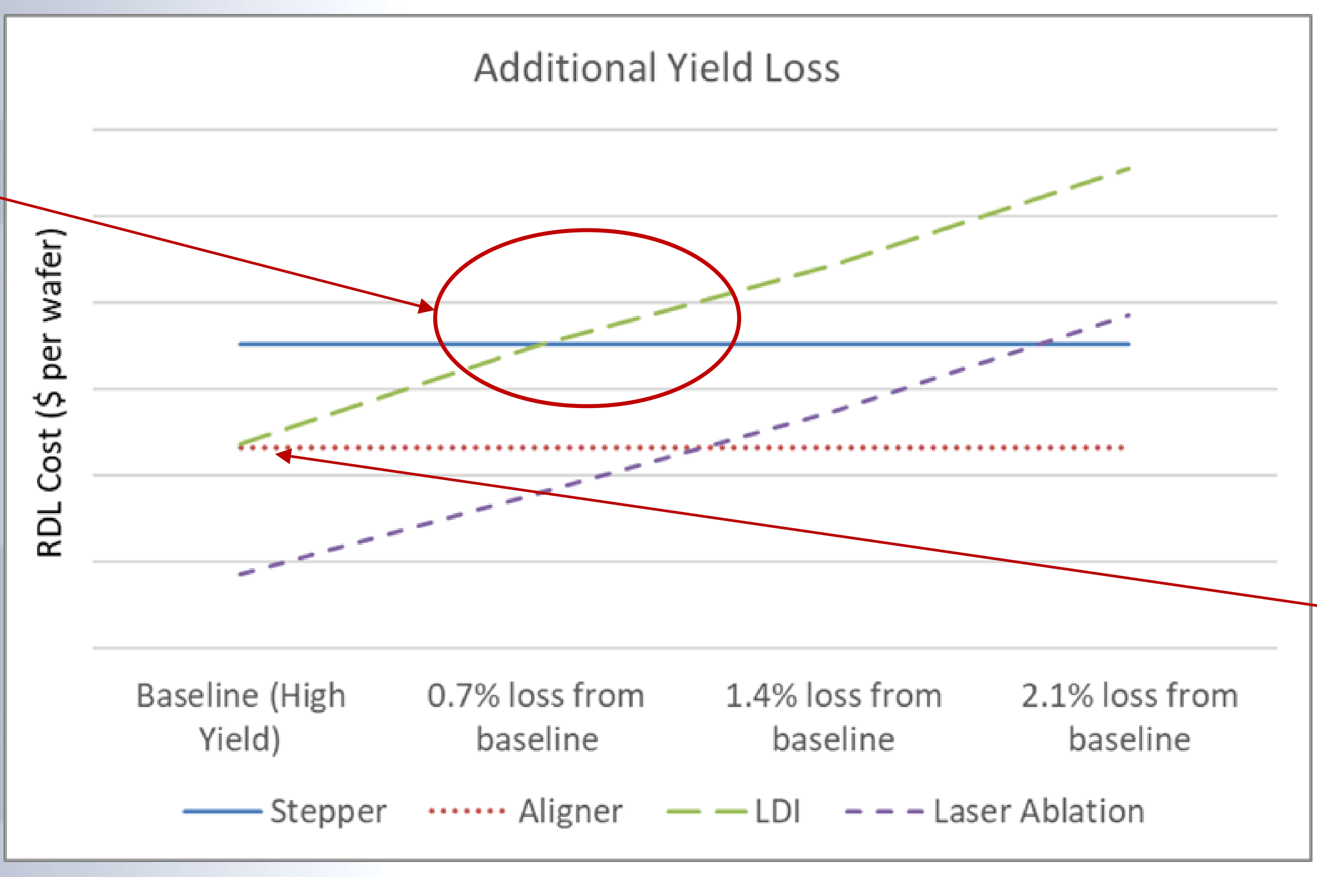
Takeaway: Throughput is a major cost driver

Sensitivity Analysis



Sensitivity Analysis

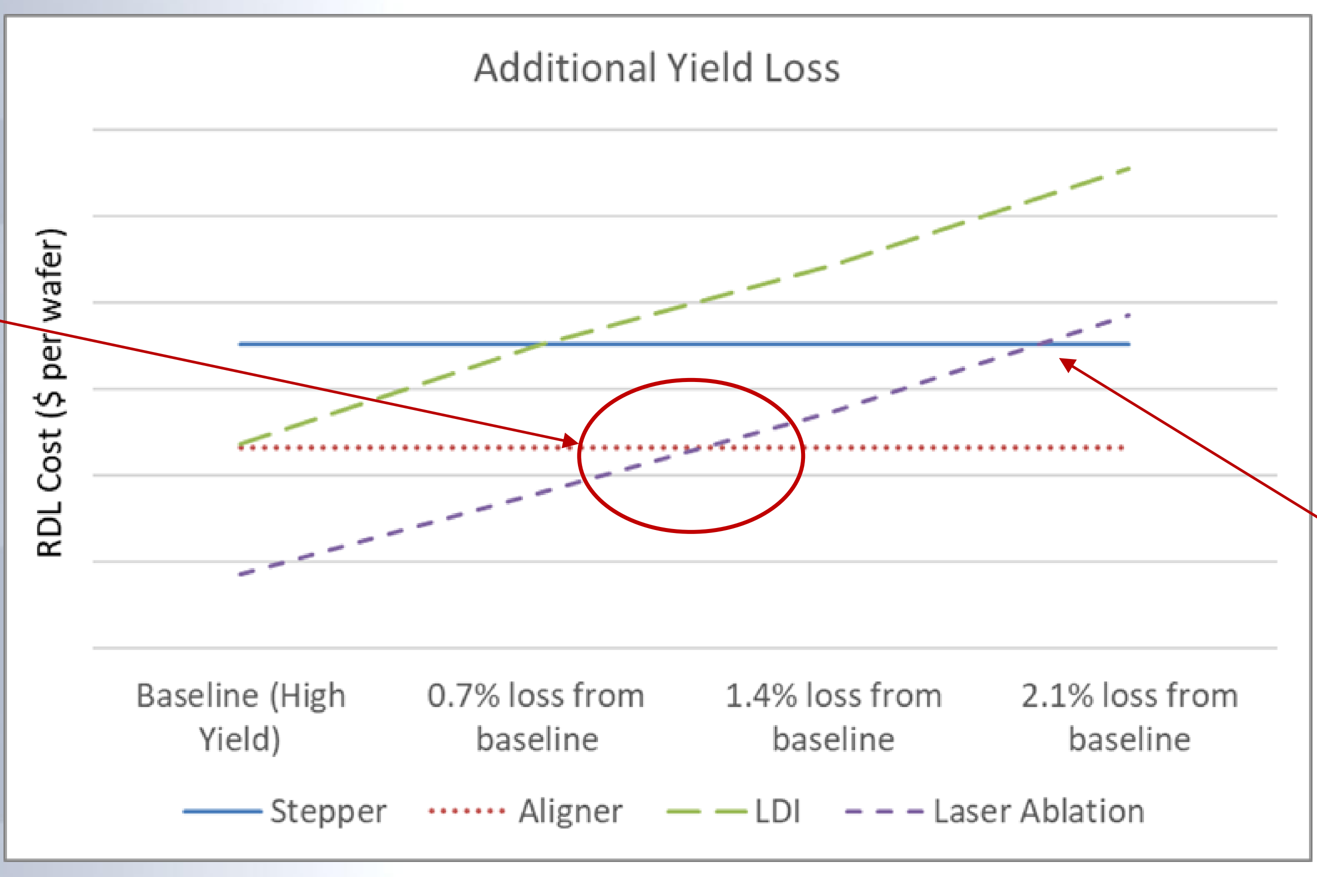
Cost of an RDL using an LDI process becomes less cost-effective than a process using a stepper with a loss of 0.7% yield.



LDI does not compete with the aligner process with any loss in yield from the baseline assumption.

Sensitivity Analysis

Cost of an RDL using a laser ablation process becomes less cost-effective than a process using an aligner with a loss of ~1% yield.



Laser ablation would no longer compete with the cost of an RDL built using a stepper, even when achieving the same throughput as a stepper at half the cost, if yield is 2% worse than the stepper process

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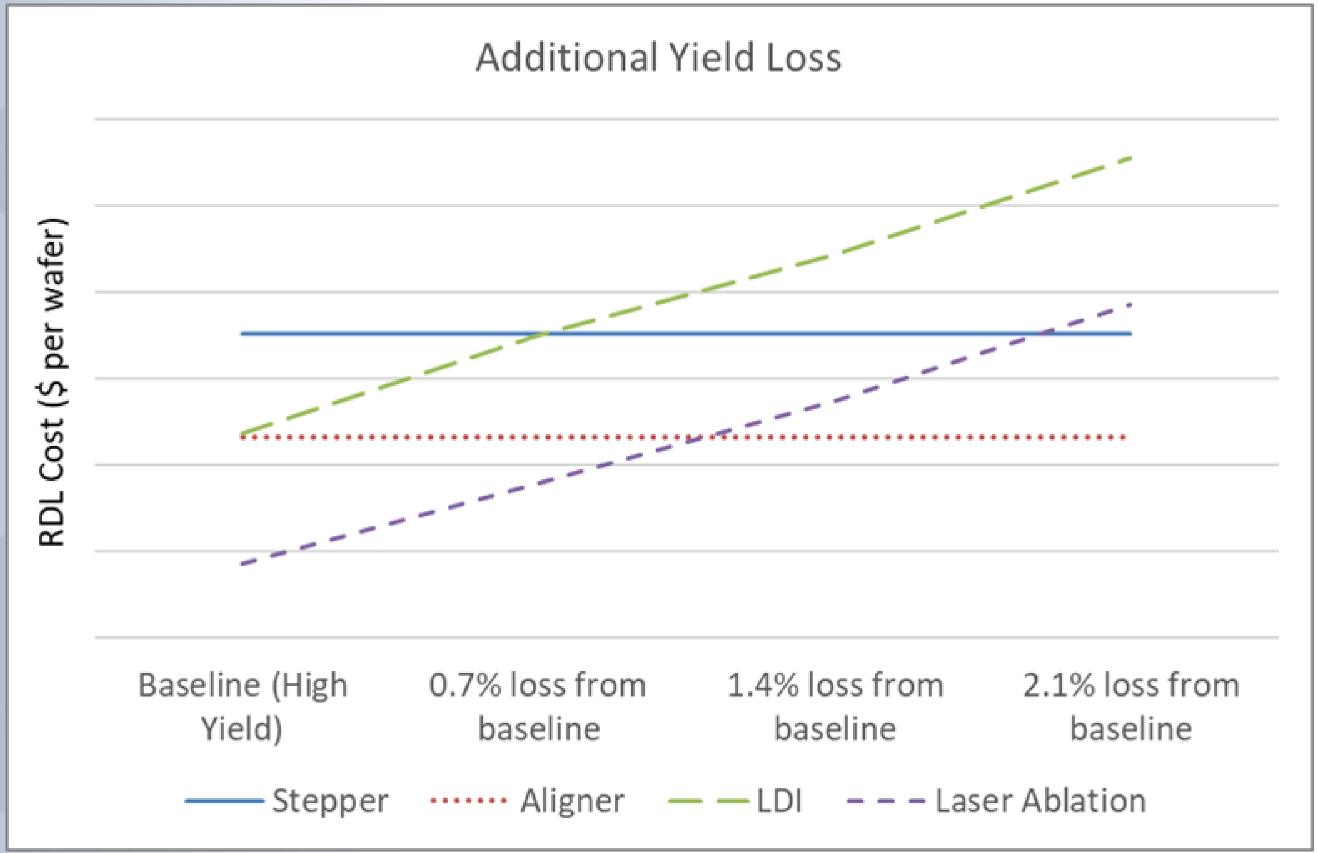
Sensitivity Analysis



Takeaway: Yield is a major cost driver

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Sensitivity Analysis

- **Three variables shown as medium/high cost drivers**
- **Impact of each variable should be considered in combination with the other variables**
  - For example, a full 2% yield loss is required for the laser ablation process to no longer compete with a stepper-based RDL
  - But what about a small yield loss, small throughput loss, and more expensive equipment?

SUMMARY

Summary

- **Under baseline assumptions, the stepper generates the most expensive RDL, and the laser ablation process generates the most cost-effective RDL**
  - Assumes laser-based processes have same yield and same throughput as a stepper, at half the cost of a stepper
- **Throughput and yield are key cost drivers**
  - Loss in throughput quickly erases the benefits of the two maskless processes
  - Small yield loss impacts the cost-effectiveness of an LDI process
  - Slightly higher yield loss needed to impact the cost-effectiveness of laser ablation compared to a stepper-based process
- **All four patterning methods are reasonable lithographic approaches to consider for a fan-out panel**
  - Any approach has the potential to be the most cost-effective – Highly dependent on design details