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# Reducing \$/Wp of Thin Film Si Through Materials Cost, Scale and Technology

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Linde Electronics

# Agenda



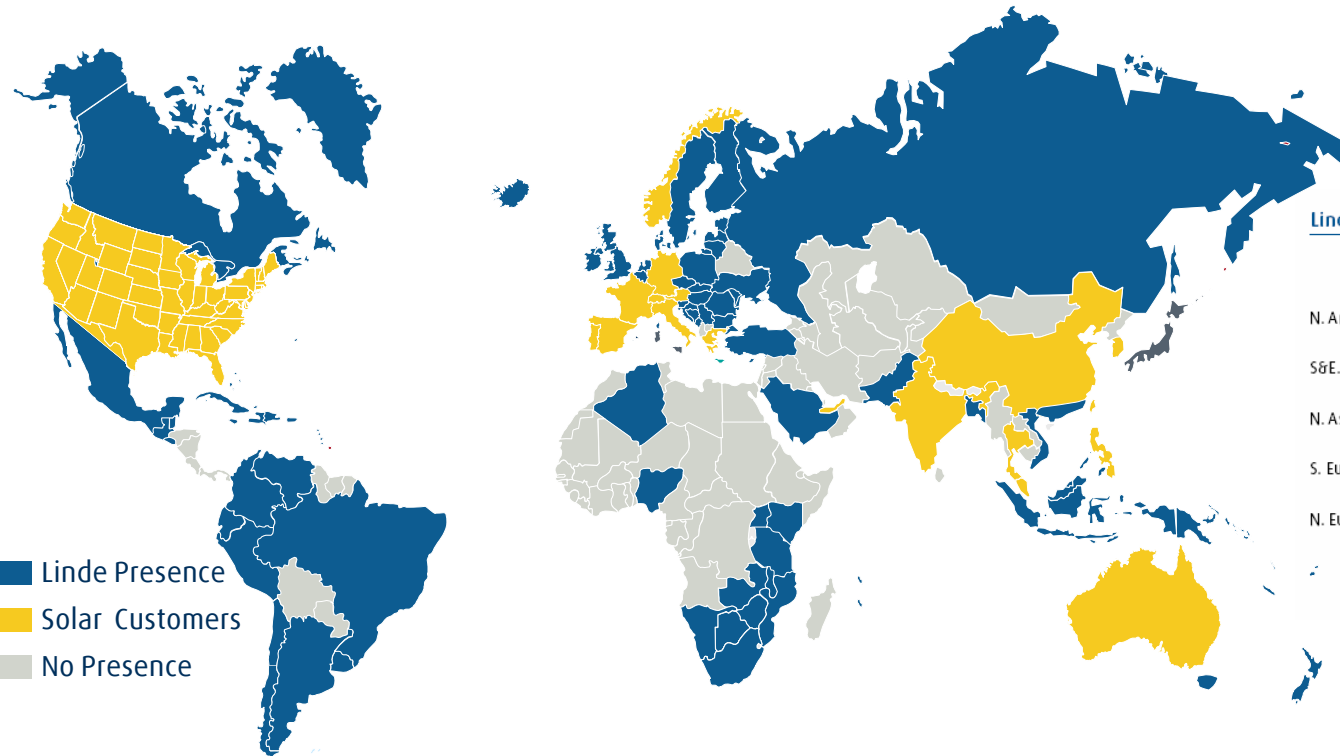
**Introduction to Linde**

**Drivers for Cost Reduction**

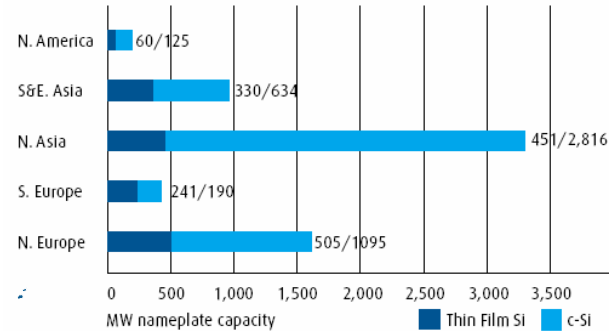
**On-Site Production of Key Gases**

**Cost Reduction Roadmap**

Linde is a \$19B global gas and engineering company with business in over 100 countries worldwide and global solar customer base



Linde PV customer base (mid 2009)



# Agenda



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**Drivers for Cost Reduction**

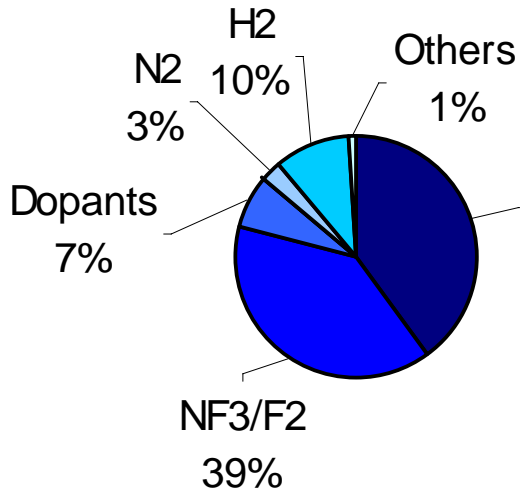
On-Site Production of Key Gases

Cost Reduction Roadmap

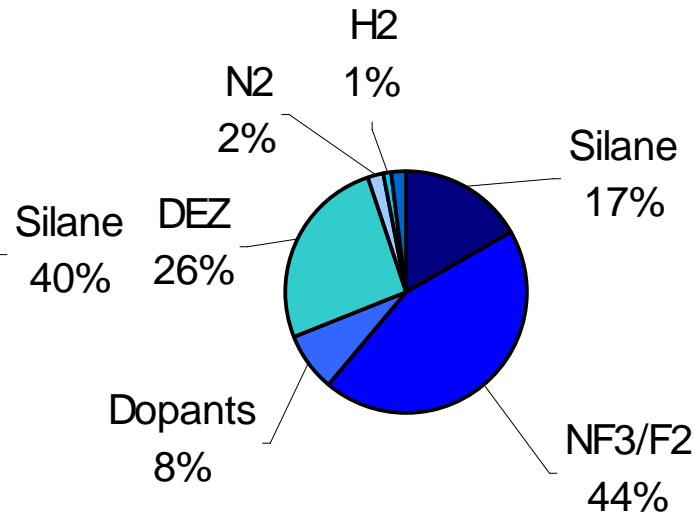
# Typical Gas Cost Breakdown for Thin Film Silicon



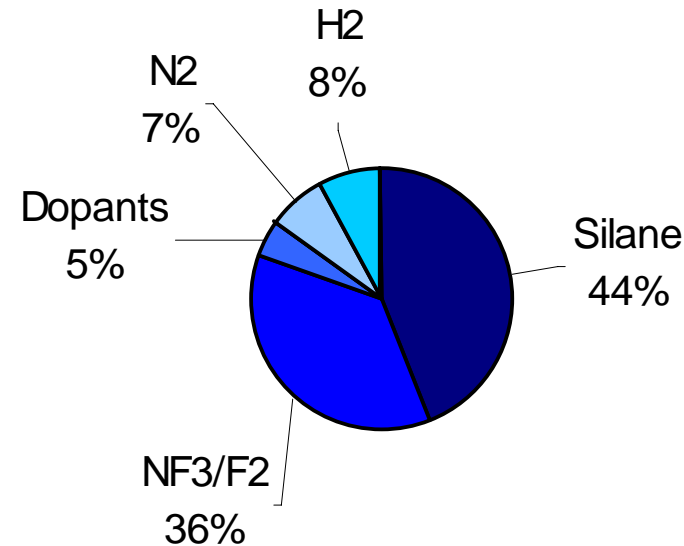
## OEM A



## OEM B

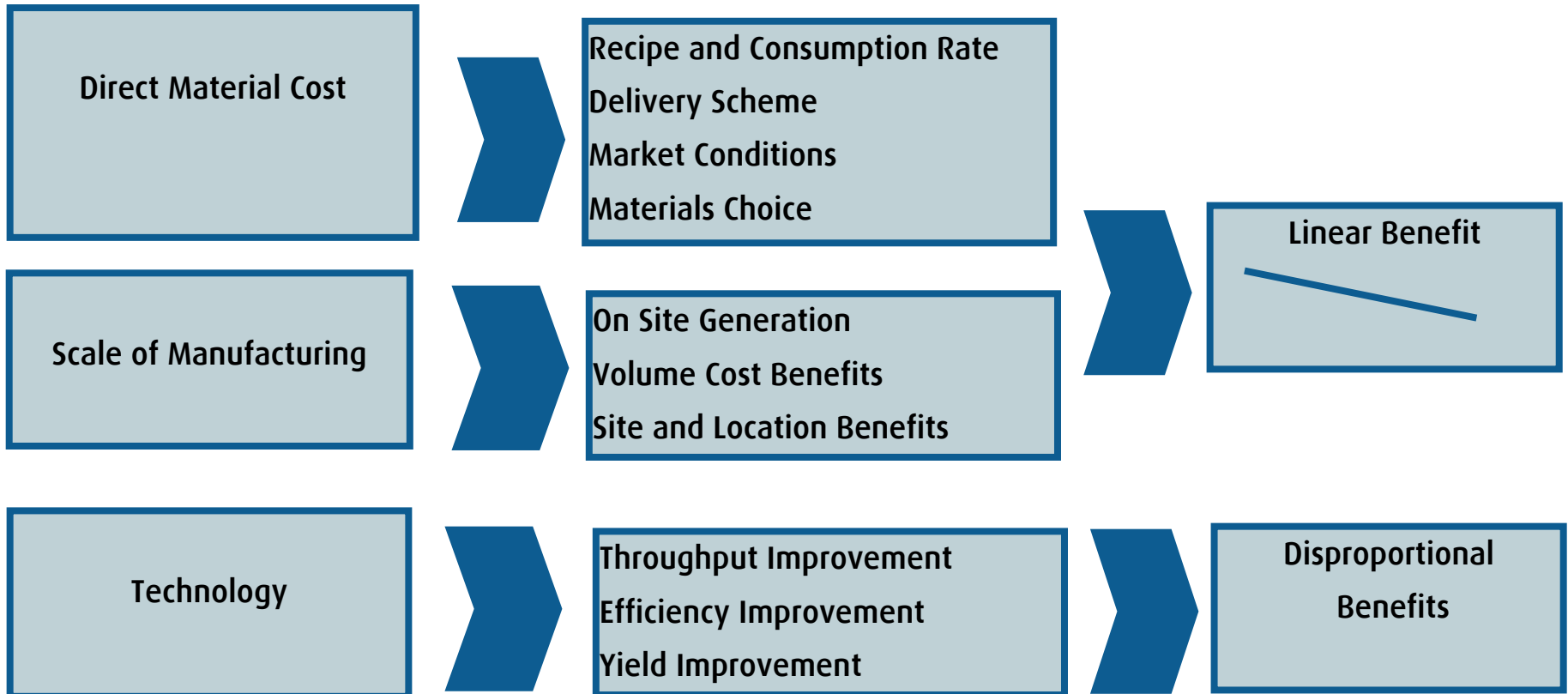


## OEM C



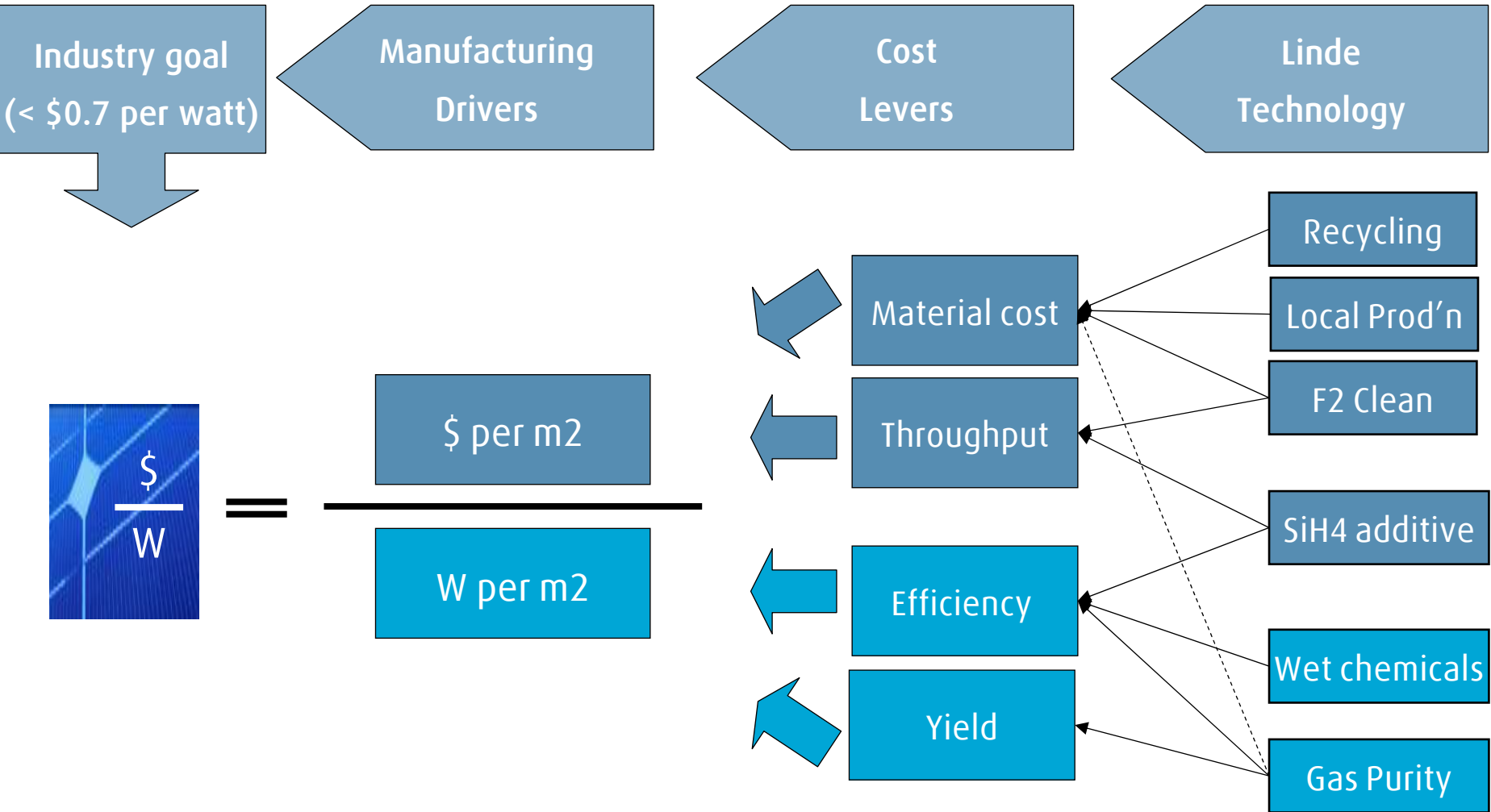
Silane, Cleaning Gas and Bulk H2/N2 are key cost components

# Factors Influencing Cost of Materials in the Process



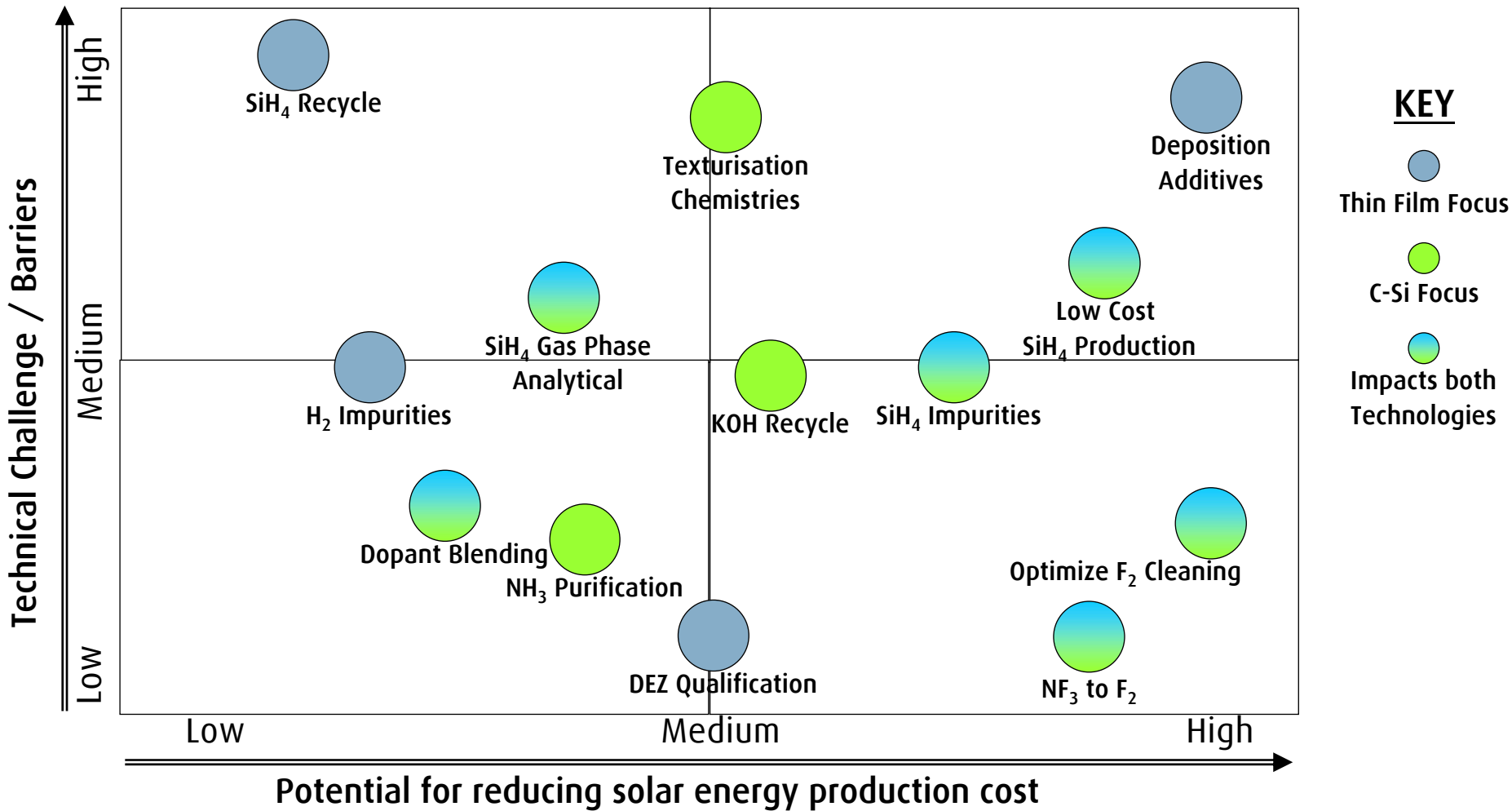
# Gases have significant impact over and above material cost

Leveraging gas technology is critical for cost reduction



# Linde Solar Technology Development Programmes

All development activity focused on reducing \$/Wp





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**On-Site Production of Key Gases**

Cost Reduction Roadmap

# Is onsite production the right choice for gases?

## Benefits

- Secure supply. No dependence on multiple weekly or daily trailer deliveries
- Lower cost. Reduced transportation costs. No liquid production cost (for H<sub>2</sub> and N<sub>2</sub>). Improved COO (F<sub>2</sub>)
- Increased safety: No frequent change-outs of toxic and flammable gas cylinders
- Reduced Carbon Footprint

## Considerations

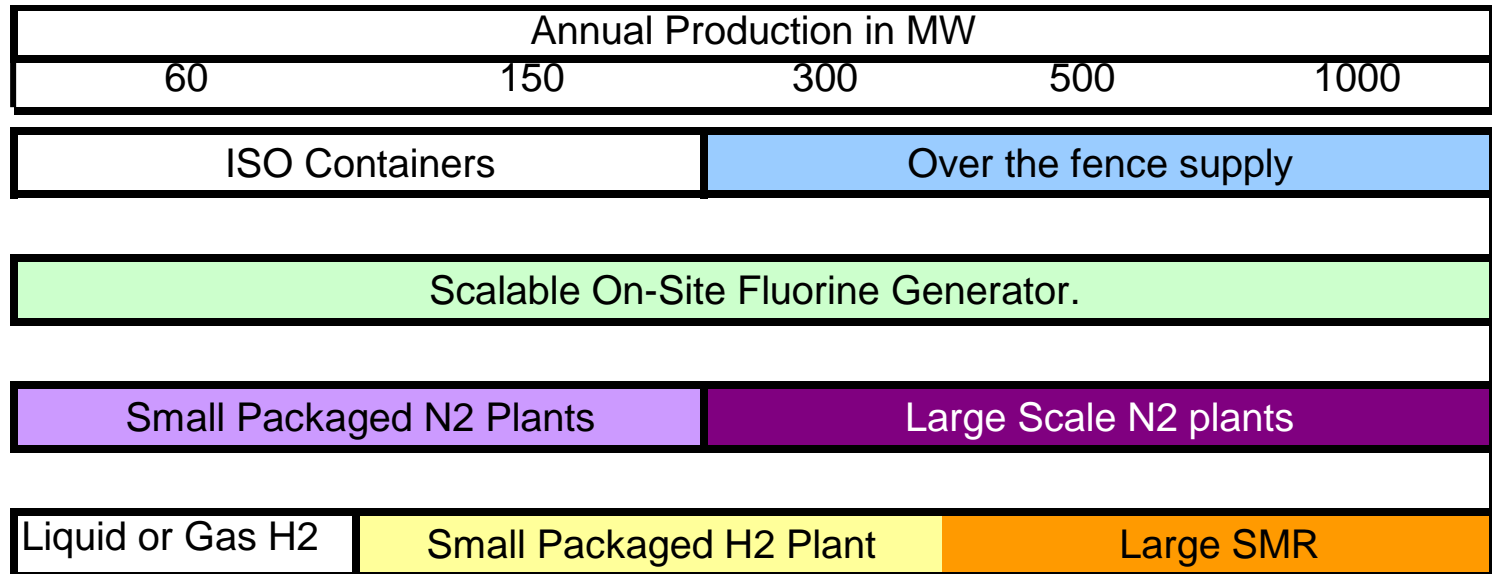
- Requires higher initial capital cost outlay for gas supplier
- Requires long term contract and minimum consumption by customer
- Requires back up schemes with on-site storage

*On-Site Gas Production can reduce cost/Wp for high volume production*

# Minimum production scale for viable on-site gas supply

Tandem Junction Silicon Process

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	MW Produced/year				
	60	150	300	500	1000
<b>Silane (MT/yr)</b>	18-60	50-150	90-300	150-500	300-1000
<b>Clean Gas (MT/yr)</b>	65-70	160-175	325-350	550-575	100-120
<b>N2 (Nm3/hr)</b>	700-900	1800-2500	3500-4500	6000-7500	12000-15000
<b>H2 (Nm3/hr)</b>	30-250	75-700	150-1500	250-2500	500-5000

Consumption rate depends on process and technology

# Silane: Current Supply Scheme



**Large Scale Polysilicon Plant**  
**>1000TPA Silane**

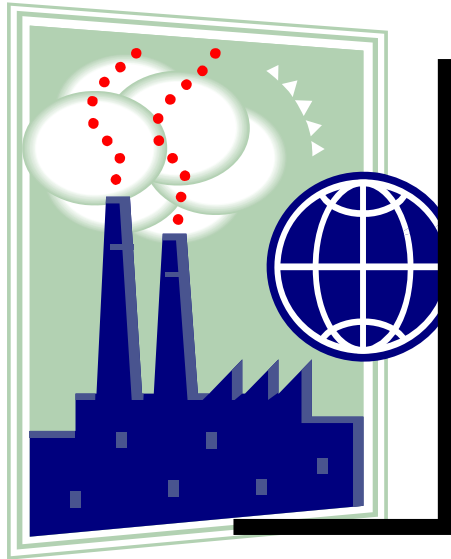
**Major Gasco transfill plant**

**Solar Cell Manufacture**  
**1-200TPA Silane**

- Most Silane is produced by major polysilicon manufacturers
- Major Industrial Gas companies purchase, repackage and deliver to end user
- Price and availability of Silane is highly variable

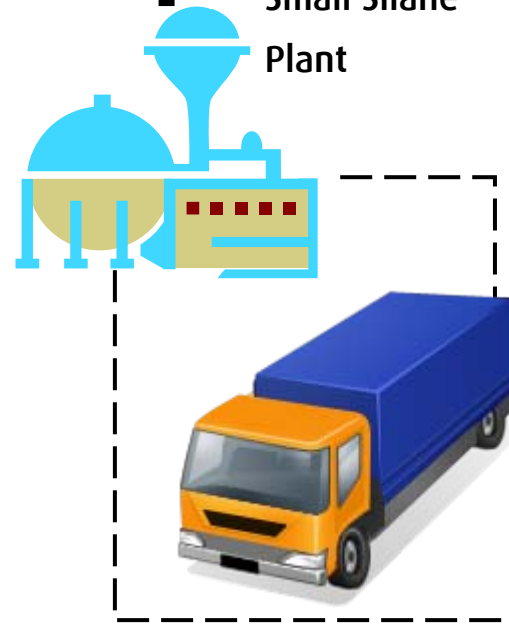
**Stable Supply and Cost Reduction requires alternative supply model**

# Distributed Silane Production and Delivery



Large Solar Cell Customer  
(>250MW)

Direct Pipeline  
Over the Fence



Small Silane  
Plant

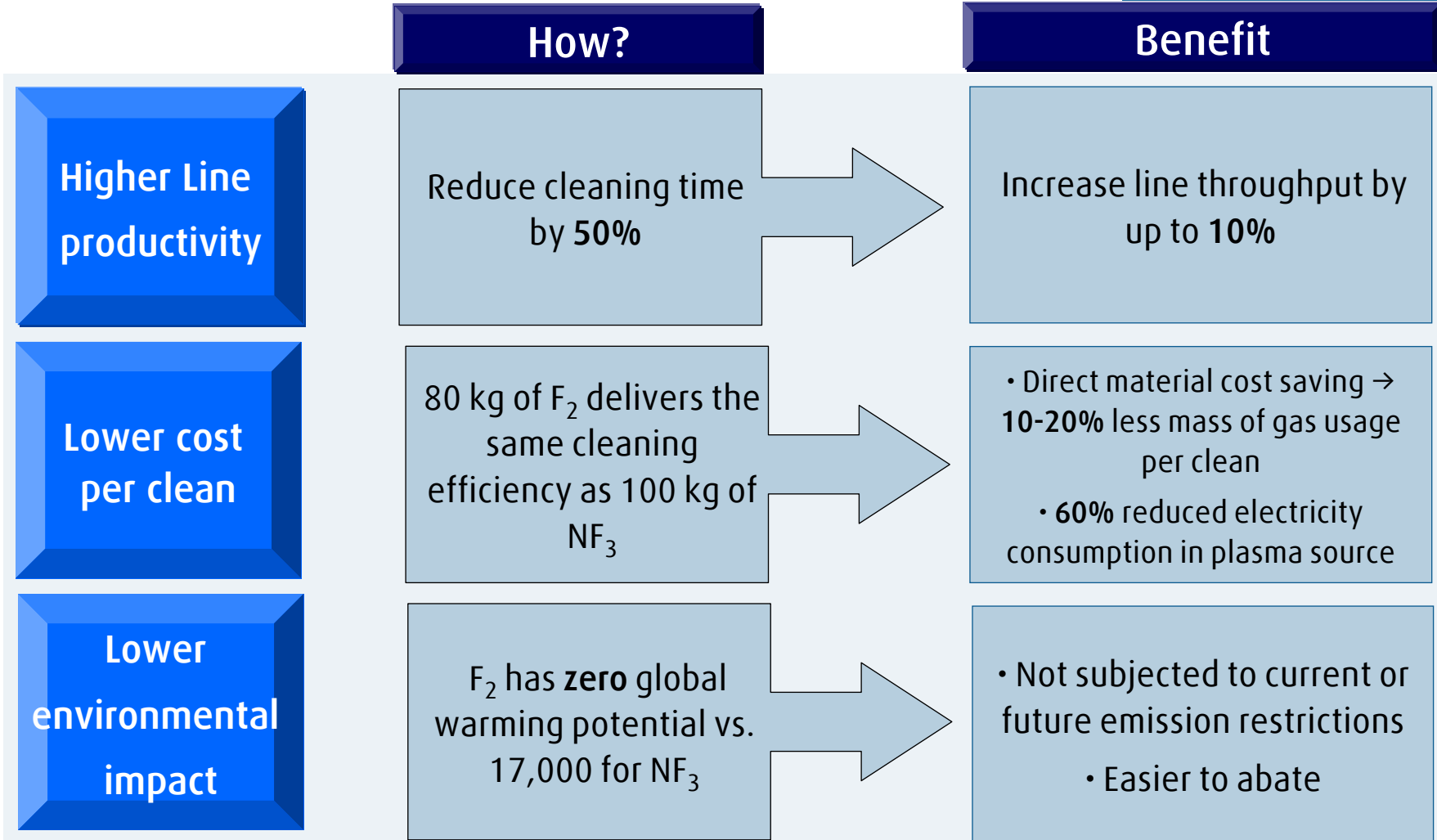
Small Solar Cell Customer

Small Solar Cell Customer

- Over the fence plus distribution
- Some risk is shared
- Gasco owns and operates Silane plant
- Customer can co invest in Silane production

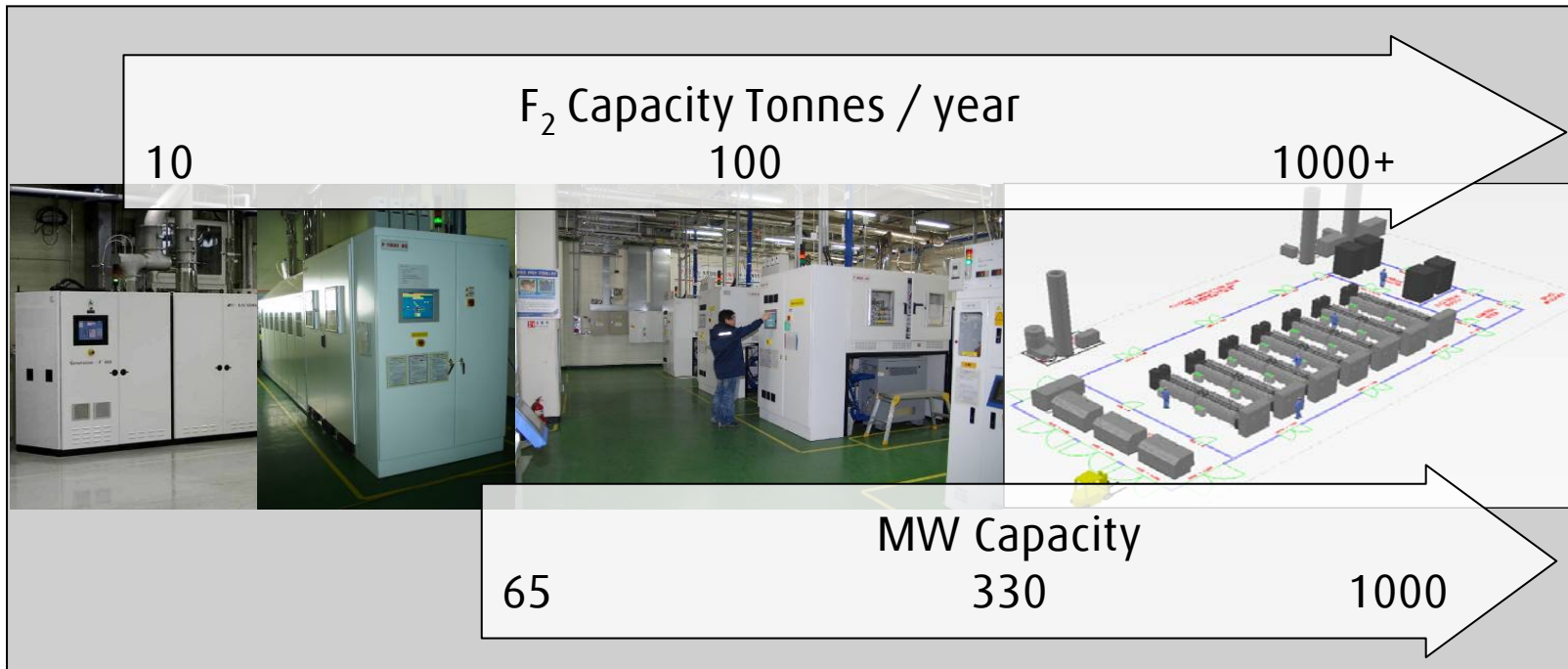
- Reduced cost of Silane
- Guaranteed supply
- Stable price
- Reduced risk during container changes
- Reduced Carbon Footprint

# Replacing $\text{NF}_3$ with On-site $\text{F}_2$ to address key throughput, cost & environmental concerns



**Modular On Site  $\text{F}_2$  Solution:**  
Eliminates logistics of trailer supply chain and guarantees security of supply

# Generation-F<sup>®</sup> - a modular solution for any thin film silicon line



MW CAPACITY	65 – 1 x TJ line	330 – 5 x TJ lines	1000 – 3 x Cluster
Tonnes / yr F <sub>2</sub>	~70	~350	~1150
Potential Saving over NF3 (\$/year)	~\$2.5M	~\$11.7M	~\$32.7M

# Nitrogen: Variable size on-site generators for all size solar fabs



Threshold for N<sup>2</sup>-Onsite depends on proximity of fab to an ASU

Liquid assist plants use delivered liquid N<sub>2</sub>. Compressor plants can operate without Liquid N<sub>2</sub>

Typical lead time of small plants is 12-18 months

Initial production ramp is managed by Liquid N<sub>2</sub> tanks

Back up is by Liquid N<sub>2</sub> tanks

Pipeline possible based on location



Packaged Liquid-assist plants  
250-2500 Nm<sup>3</sup>/hr



Packaged Compressor plants  
350-3500 Nm<sup>3</sup>/hr



Large scale ASU  
4200-15000 Nm<sup>3</sup>/hr



- Is it possible to get Liquid H<sub>2</sub> delivery? For example in EU and US, LH<sub>2</sub> is readily available but not so in Asia.
- Proximity to H<sub>2</sub> plant
- Natural Gas availability and quality
- Ramp schedule and full production demand
- Back up schemes with liquid or compressed H<sub>2</sub>

## • Basics of On-Site H<sub>2</sub> Generation

- Smaller scale H<sub>2</sub> in remote regions can be produced by water electrolysis (< 50 Nm<sup>3</sup>/hr)
- On larger scale, H<sub>2</sub> is generated from Natural Gas (CH<sub>4</sub>)
- $\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow \text{CO}_2 + 3\text{H}_2$
- Quality of H<sub>2</sub> and purification requirements depends on quality of Natural Gas
- Other possible fuel sources include methanol and higher hydrocarbons

# Hydrogen – large consumption drives on-site generation

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## Single Junction



- <math>80 \text{ Nm}^3/\text{hr}</math>
- Tube trailer/Liquid H<sub>2</sub>/Electrolyser
- 3-6 months Leadtime

## Tandem Junction < 300 MW



- 80-1000 Nm<sup>3</sup>/hr
- Small Packaged SMR
- Tube trailer back-up
- ~12 months leadtime

## Tandem Junction > 300 MW



- 1000-4,200 Nm<sup>3</sup>/hr
- Large SMR
- 18-24 months leadtime

- Hydrogen pipeline supply may be possible depending on location.
- Natural Gas feedstock supply is critical to low cost production via SMR

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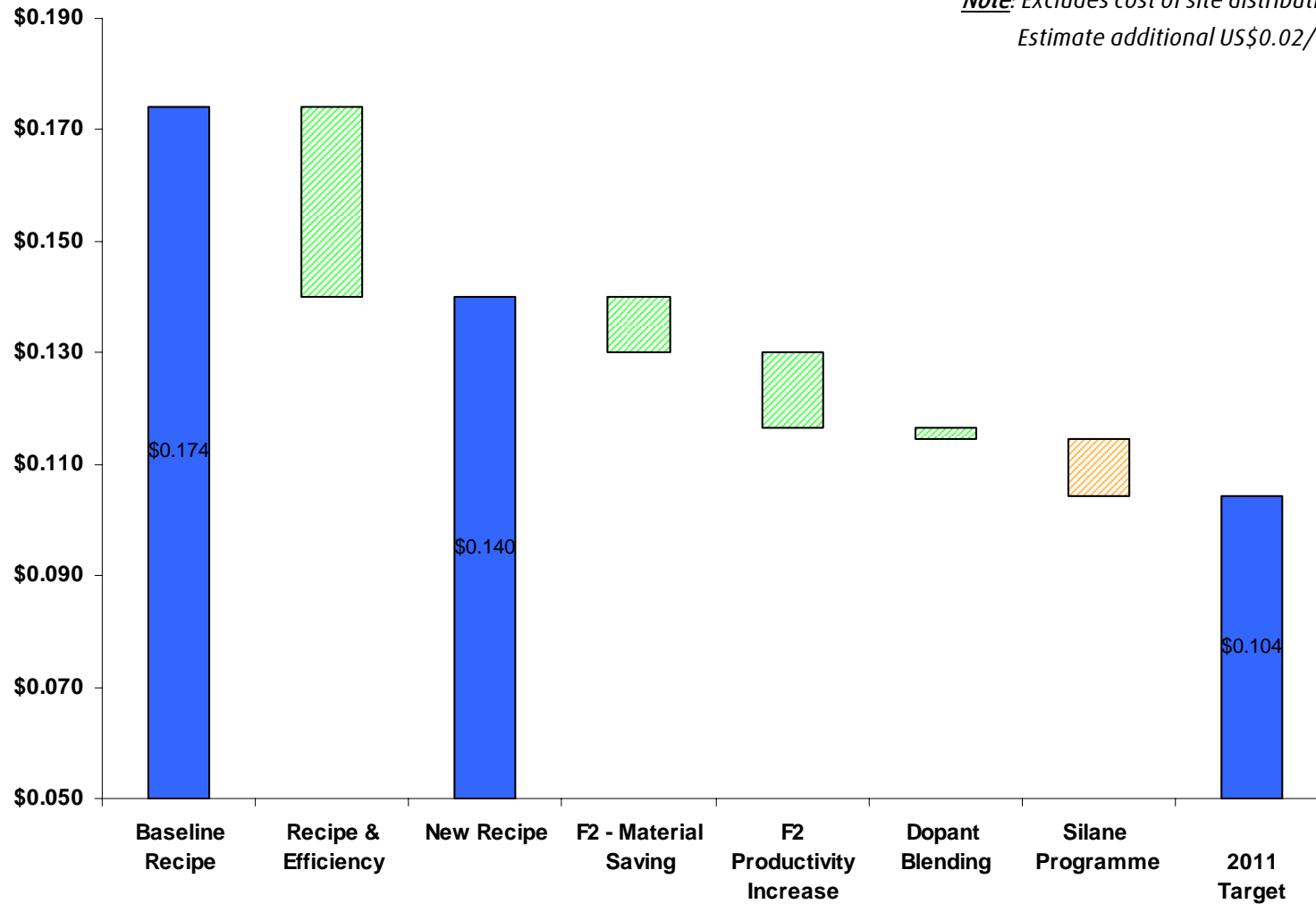
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**Cost Reduction Roadmap**

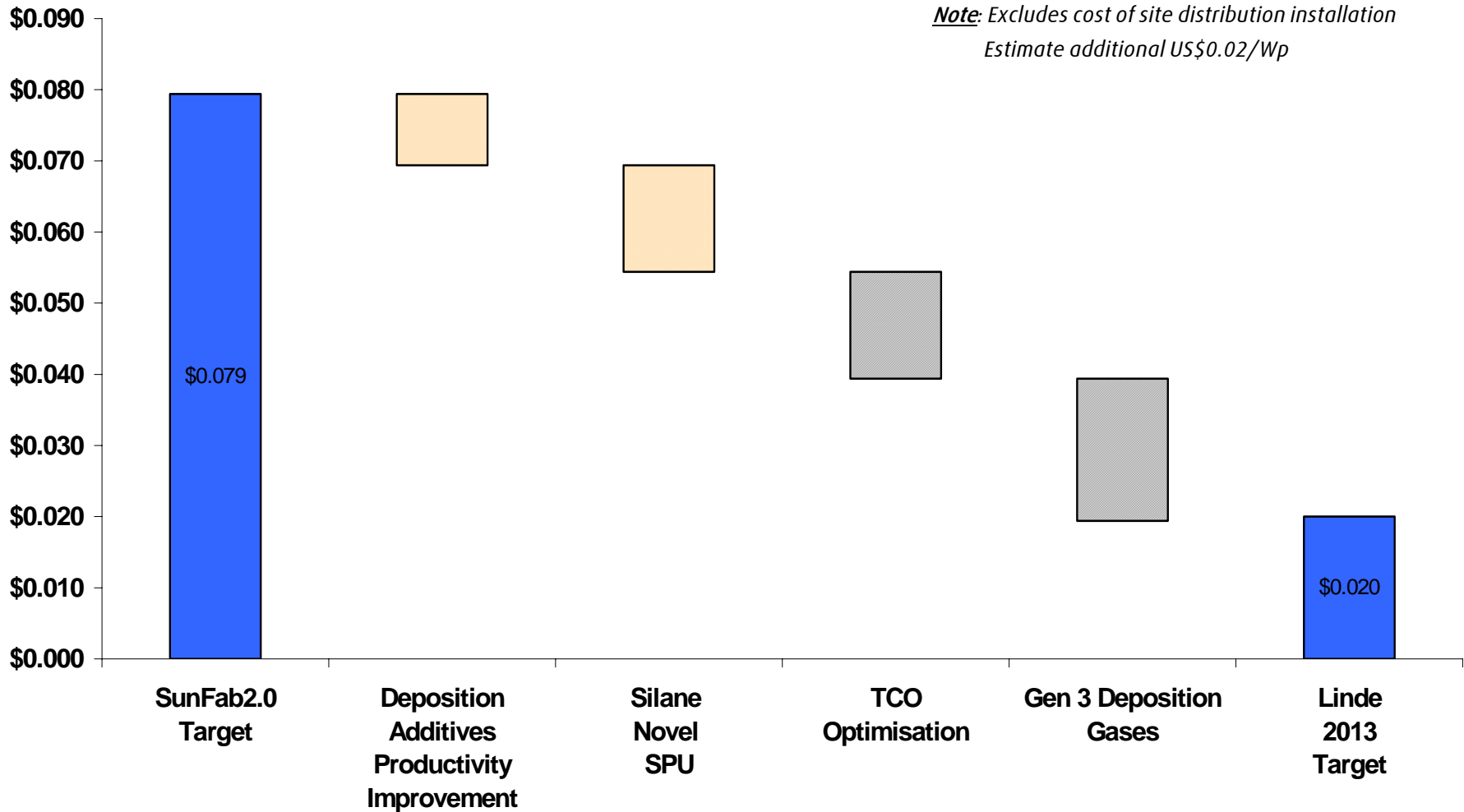
# Gases Value Improvement per Wp - 2011 Roadmap.



*Note: Excludes cost of site distribution installation  
Estimate additional US\$0.02/Wp*



# Gases Value Improvement per Wp - 2013 Roadmap.



**Gases have a disproportionate influence (more than just material cost) on total cost of production of thin film silicon solar cells**

**Gas technologies affect throughput, efficiency and yield**

**On-site plants for critical gases are necessary to meet logistical and cost challenges.**

**On-site production threshold depends on several factors**

- Technology of choice and gas consumption rates
- Planned scale of operation
- Proximity to Bulk Gas Manufacturing locations

**Work closely with gas supplier through the planning process to determine needs**

# Contact



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