Changing wafer size

25 March 2021





Our Vision

A sustainable future with clean energy for all.

Our Mission

To be a leading manufacturer of silicon ingots and wafers for premium solar cells, through innovative technology, sustainable production and operational excellence.

Our Values

Dedication, Innovation, Inclusivity and Integrity

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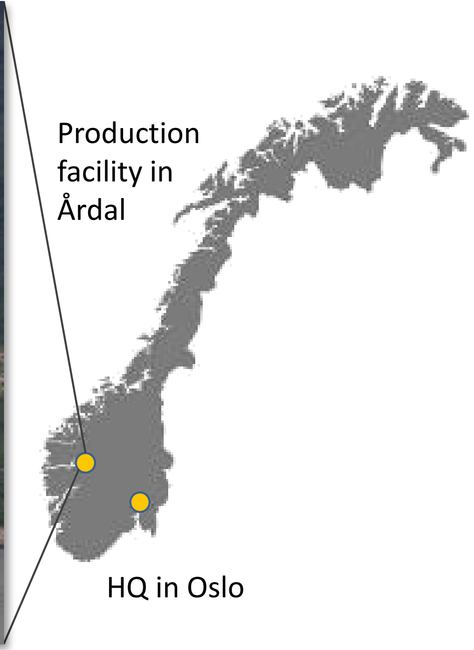
NorSun is the leading ingot and wafer manufacturer in Europe

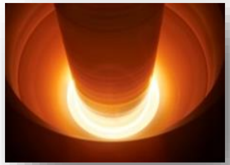
Company overview

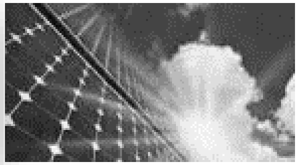
- Production of premium monocrystalline silicon ingots and wafers
- Capacity being expanded to 1 GW
- Long-time supplier to tier-1 solar cell manufacturers
- Uniquely low CO_2 footprint based on hydropower and natural cooling water
- 230 employees



NorSun solar value chain position

Polysilicon	Ingots & Wafers	Cells & modules





Premium products: NorSun
- **Highest efficiency**
- **Lowest CO_2 footprint**
- **Extensive track record**

Strong owners

- Nysnø Climate Investments: 18.3%
- ABN AMRO Energy Transition Fund: 18.3%
- Scatec Innovation: 15.7%
- Arendals Fossekompani: 15.7%
- Others: 32%

NorSun provides low CO_2 footprint value – a competitive advantage

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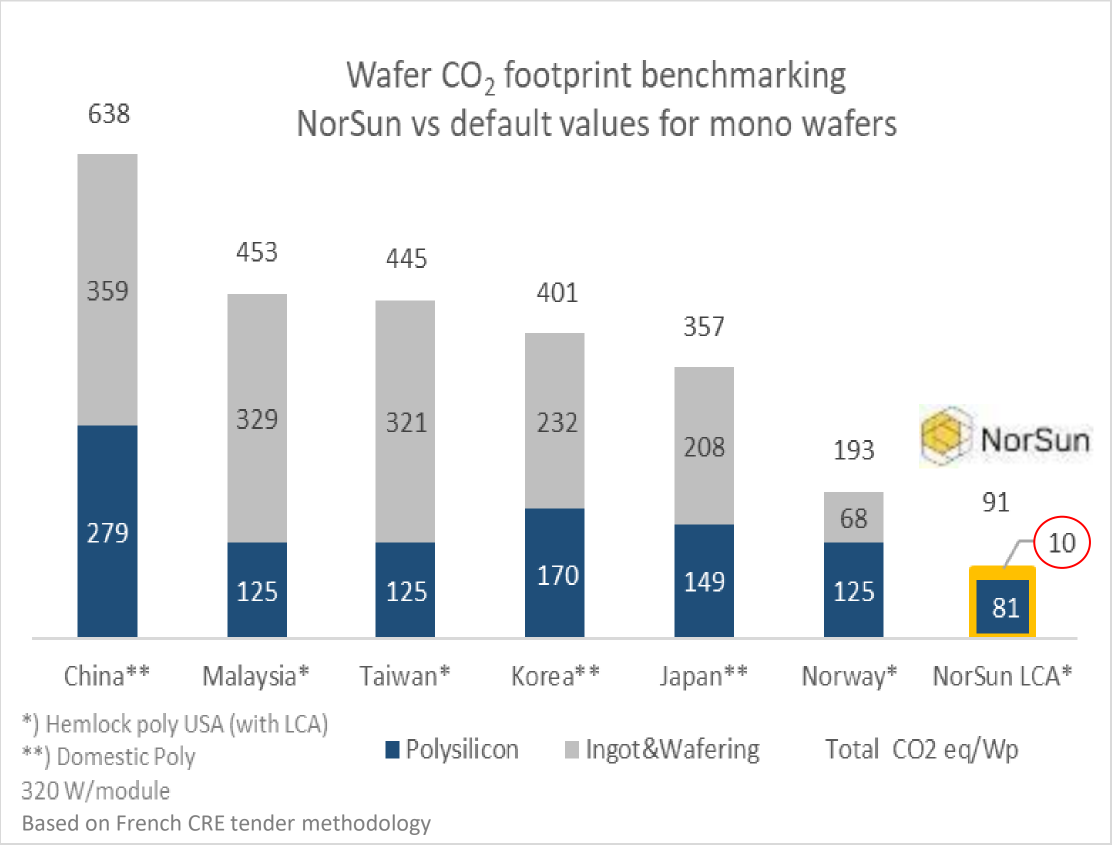
NorSun with industry leading CO_2 footprint (grams CO_2/Watt)

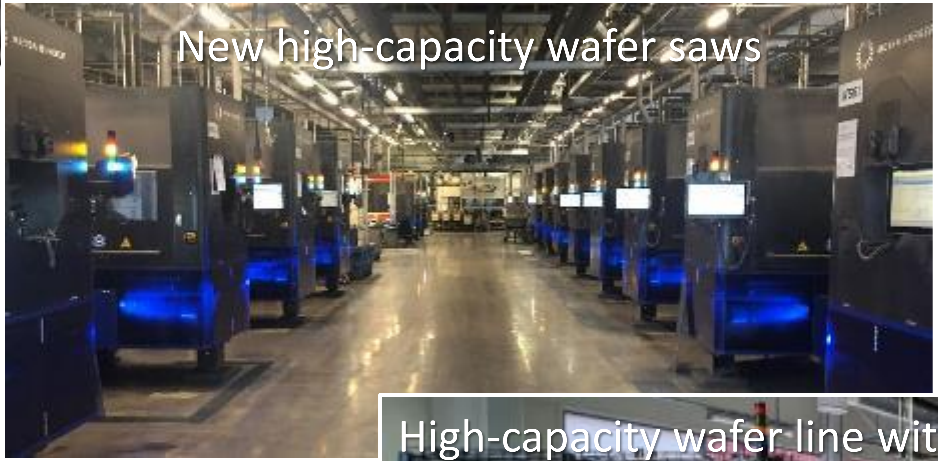


- French tenders value CO_2 footprint of the modules
  - CO_2 footprint/Watt = 20%-30% of score

- Hydro power
- Readily available cooling water reduces electricity consumption for chillers
- High quality wafers for highest cell efficiency => improving silicon per Watt
- Efficient recycling process for silicon off-cut in ingot manufacturing (such as ingot tops, tails, side-cuts and off-spec material)
- Efficient sawing process with thin diamond wire (reducing waste)
- Thin wafers down to 130µm (reducing material consumption)
- Minimal use of chemicals

Phase 1 expansion

- Increasing capacity to 1 GW and reducing unit costs through increased throughput and automation



Next step: Grow towards 4-5 GW and further reduce costs

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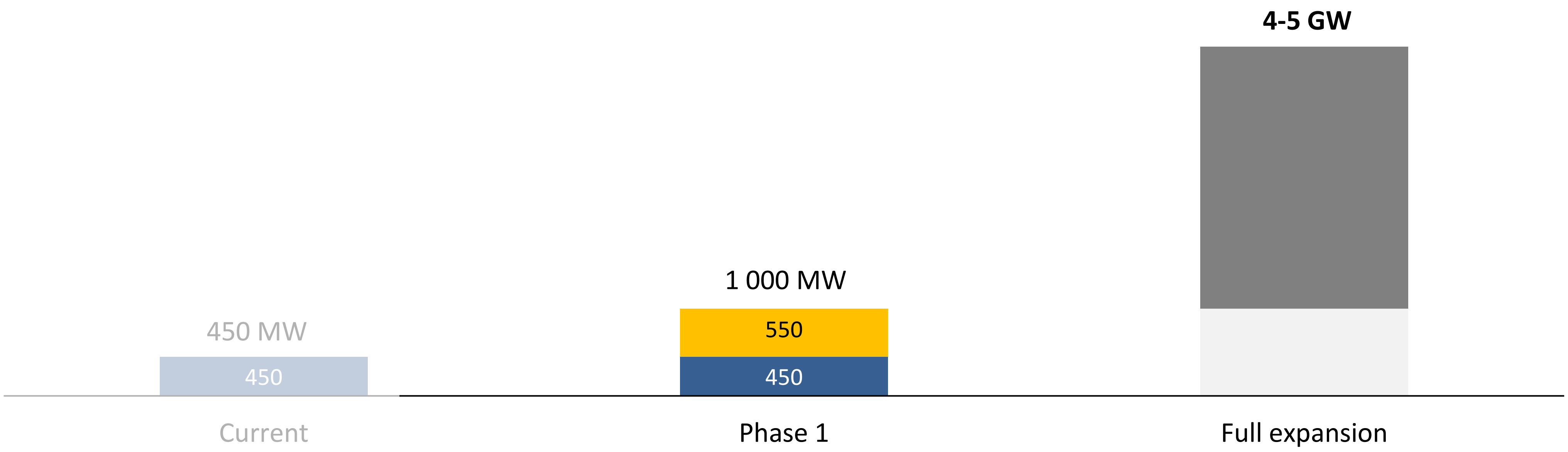


Current

- 450 MW current capacity
- Continued development of plant with first production in 2008 (nominal capacity of 150MW)

Now

Phase 1

- Upgrade and debottlenecking of existing plant
- New capacity from next generation pullers, shaping and wafering equipment
- Clear road map to further cost improvements

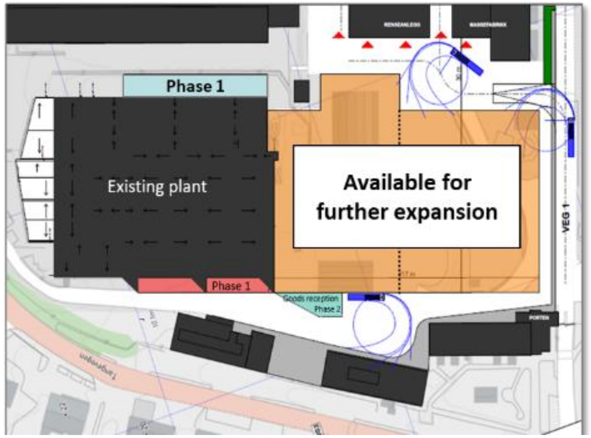
Full expansion

- Significant potential at current site for 4-5 GW capacity, with LOI for expansion signed
- World-class scale of sustainable production within n-type mono segment
- Further strengthening of cost position

Phase 2 Expansion to 4-5 GW – compatible with M10/G12 wafer formats

Phase 2 will give NorSun a world-class scale

- Required to grow with customers and market
- Access to land in place
- Pre-project started
- Financing activities to start later in 2021
- Finalization in 2023

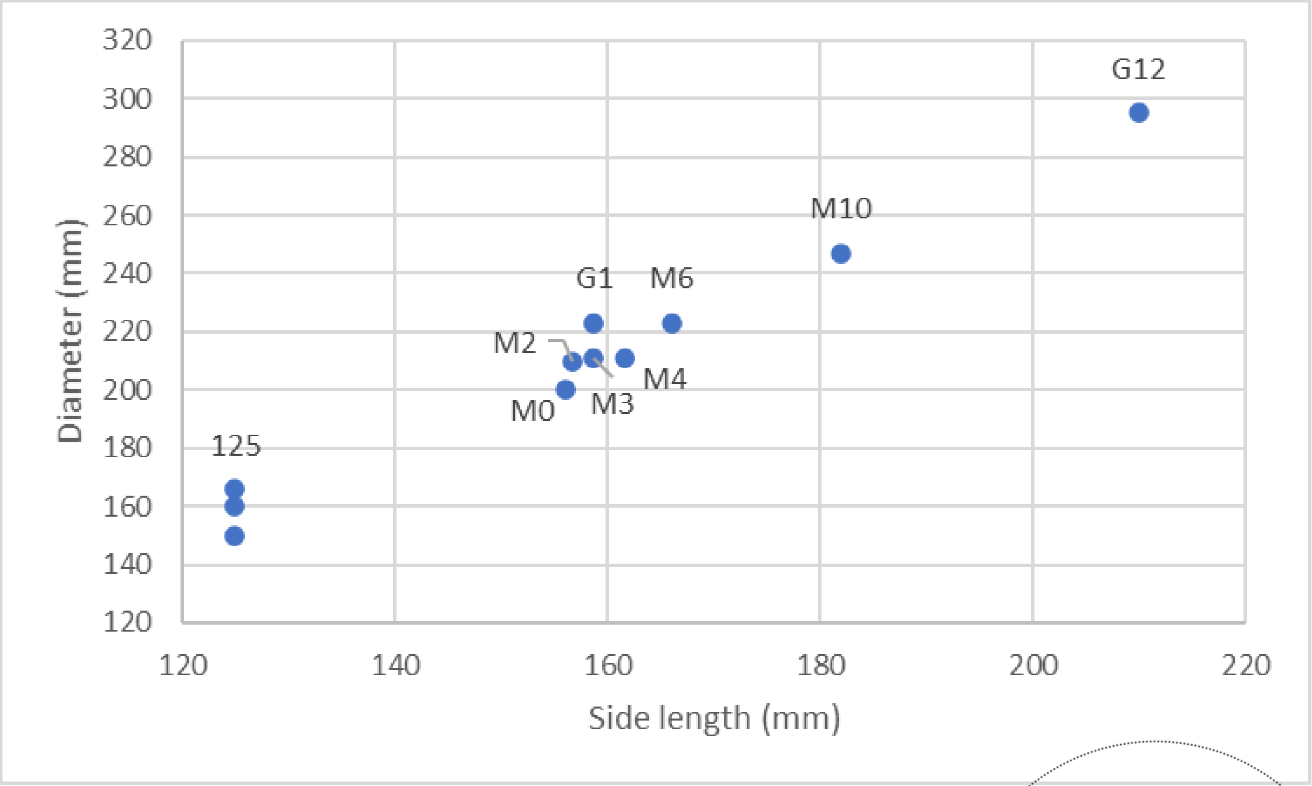


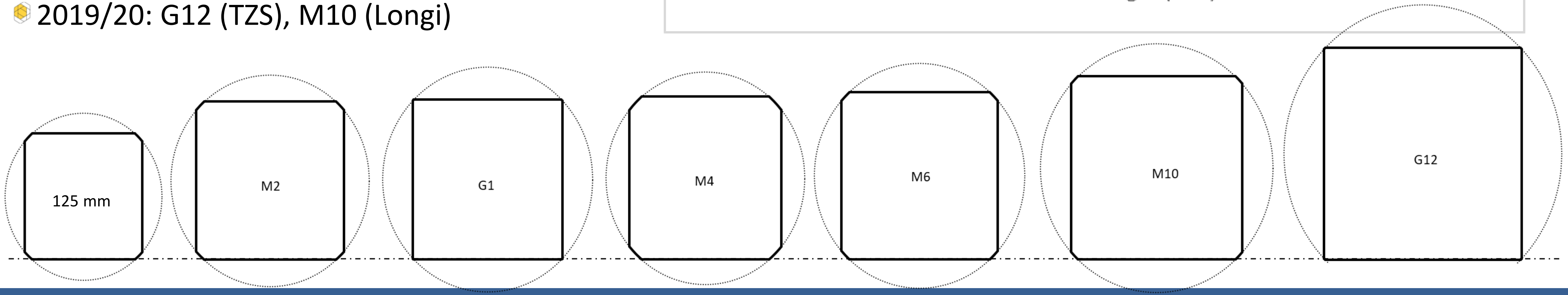
Based on own technology and innovation

- Highest ingot productivity – highest material quality - safe operations
  - Hot zone design developed by NorSun
  - Adaptive controls with AI developed by NorSun
  - Fail-safe active ingot cooling system developed by NorSun
- Processing of ingots into wafers by use of latest diamond wire technology
  - High capacity – world class tools
  - Ultra-thin wire enabling reduced waste and improved carbon footprint
- Recycling and reuse of waste
  - Recycling and reuse of excess material
  - Kerf recycling
  - Reuse of input factors, e.g. argon
- High degree of automation enabling reduction of labour
  - Full automation
  - Optimized material flow

Wafer Size Development

- Until 2010: 125 mm standard
- 2013 – Adoption of 200 mm ingot size
  - M0 format (156 / 200)
  - Standardization driven by Chinese manufacturers (LONGi, TZS, Jinglong, Solargiga, Comtec)
- 2015/16: Conversion to M2 (156.75 / 210)
- 2018/2019
  - Drive to increase module power
  - ➔ cell efficiency increase difficult with p-PERC
  - ➔ wafer size increase (+ half cut cells)
  - ➔ G1, M4, M6
- 2019/20: G12 (TZS), M10 (Longi)





How to square the circle? Ingots are round but solar panels are square

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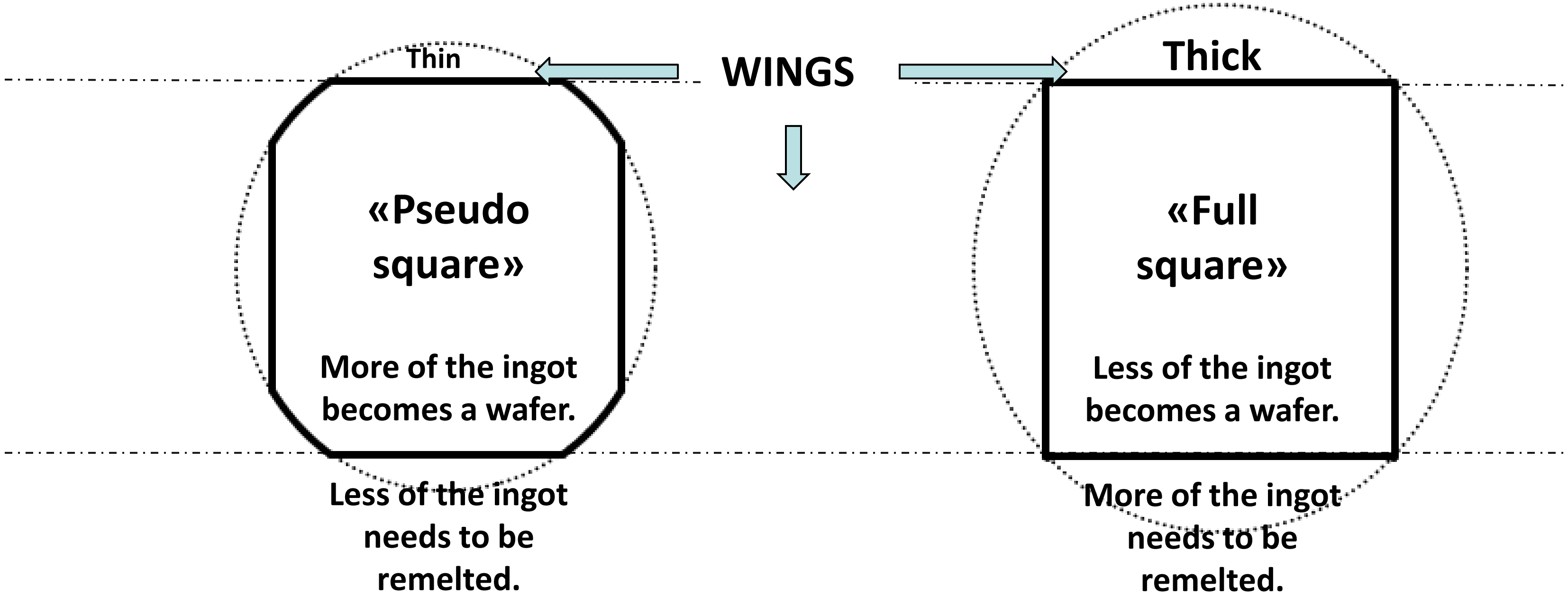
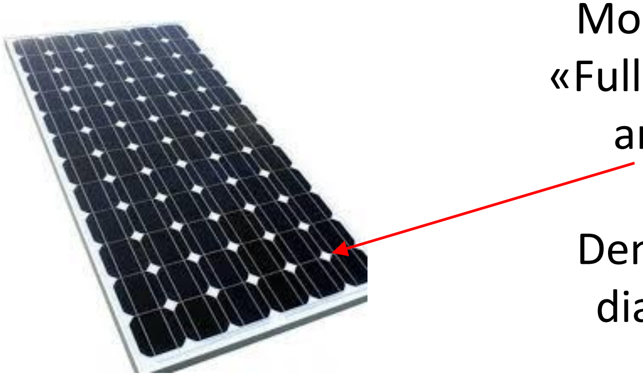
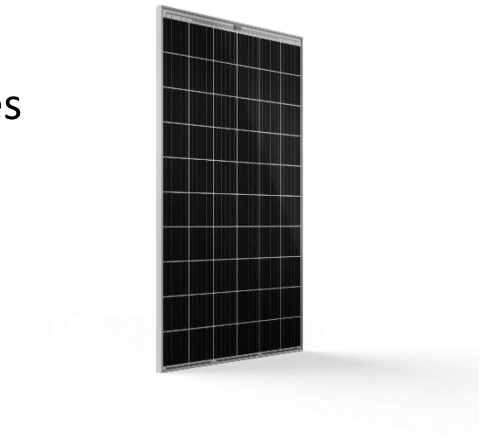


Ingot top and tail also become larger for larger diameter ingots
=> more of the ingot needs to be remelted



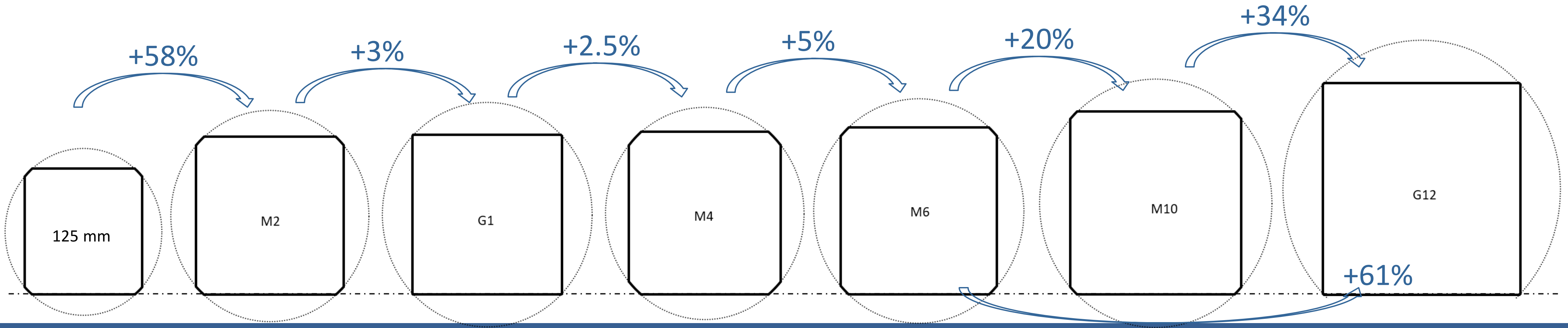
Module manufacturers would like «Full square» in order to avoid holes and maximize area utilization.

Deminishing returns of increasing diameter for small power gains.



Wafer Size

Wafer format	side length (mm)	diameter (mm)	Area (mm2)	*increase*	*increase vs. M2*	*increase vs. M6*	Area utilization	Area/ circle
125	125	166	15,506		*-36.5%*	*-43.4%*	0.9924	0.716
M0	156	200	23,895	*54.1%*	*-2.2%*	*-12.8%*	0.9819	0.761
M2	156.75	210	24,432	*2.2%*		*-10.9%*	0.9943	0.705
M3	158.75	211	25,015	*2.4%*	*2.4%*	*-8.8%*	0.9926	0.715
G1	158.75	223	25,199	*0.7%*	*3.1%*	*-8.1%*	0.9999	0.645
M4	161.7	211	25,825	*2.5%*	*5.7%*	*-5.8%*	0.9877	0.739
M6	166	223	27,415	*4.6%*	*12.2%*		0.9949	0.702
M10	182	247	33,015	*19.8%*	*35.1%*	*20.4%*	0.9967	0.689
G12	210	295	44,096	*33.6%*	*80.5%*	*60.8%*	0.9999	0.645



Driving Forces

- Cell and module production

  - Cell line throughput: W_p/h
    - Limited by piece per hour as long as production line can handle increased size
    - W_p scales with wafer area

  - Module production: W_p/h
    - Same number of cells per module
    - Same number of components, slightly increased sizes

    - Marketing: Competition to reach highest W_p per module !

- LCOE (Levelized cost of electricity), BOS (Balance of system)
  - More W_p per module
  - Similar system component costs
  - Similar installation and handling costs

➔ Reduced cost per installed W_p

Fundamental advantages of larger wafers in ingot and wafer production

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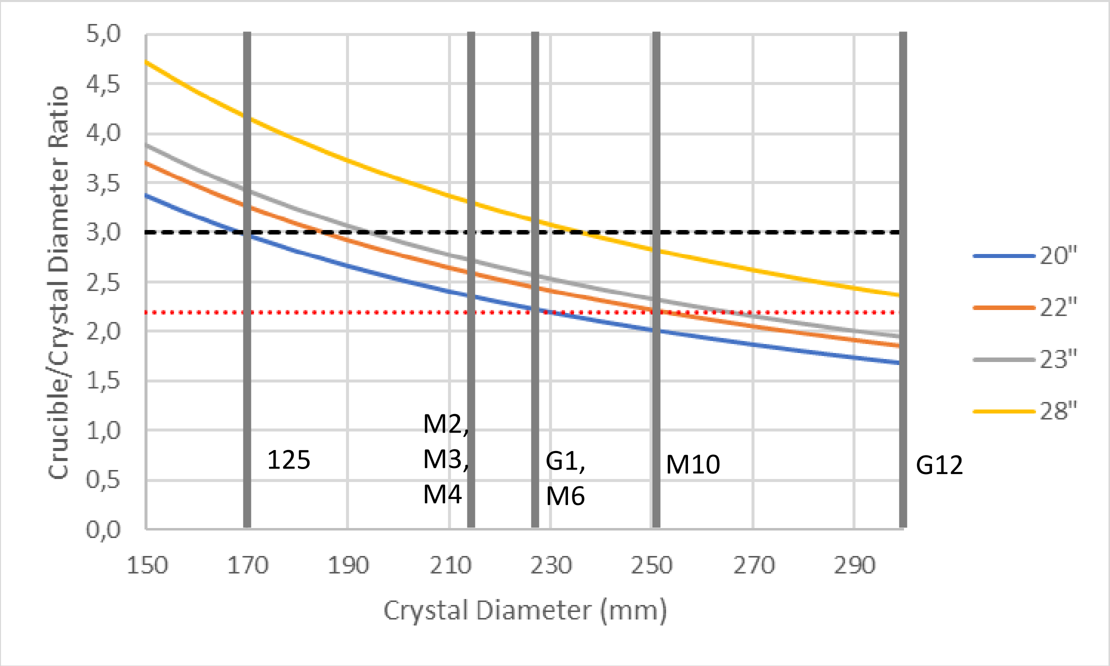
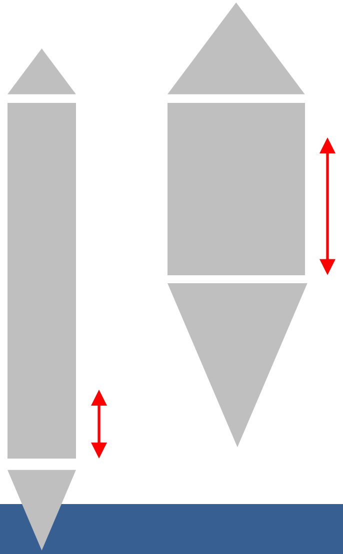
- Pulling
  - Larger diameter => higher pull speed measured in kg/time
  - Increasing crucible size to maintain the ingot length, as long as the puller is capable to handle the diameter and weights
- Shaping
  - Larger wafer area => less area to shape
  - Fewer (but heavier) blocks to handle
- Wafer saw
  - Cutting time scales with less than area (mainly with side length)
  - More wafer area from each cut => less handling, we get more wafer area out of each pit stop
- Waferline
  - Fewer wafer pcs per wafer area => higher productivity of singulators, batch tools, inspection, packing.

Fundamental **challenges** of larger wafers in ingot production

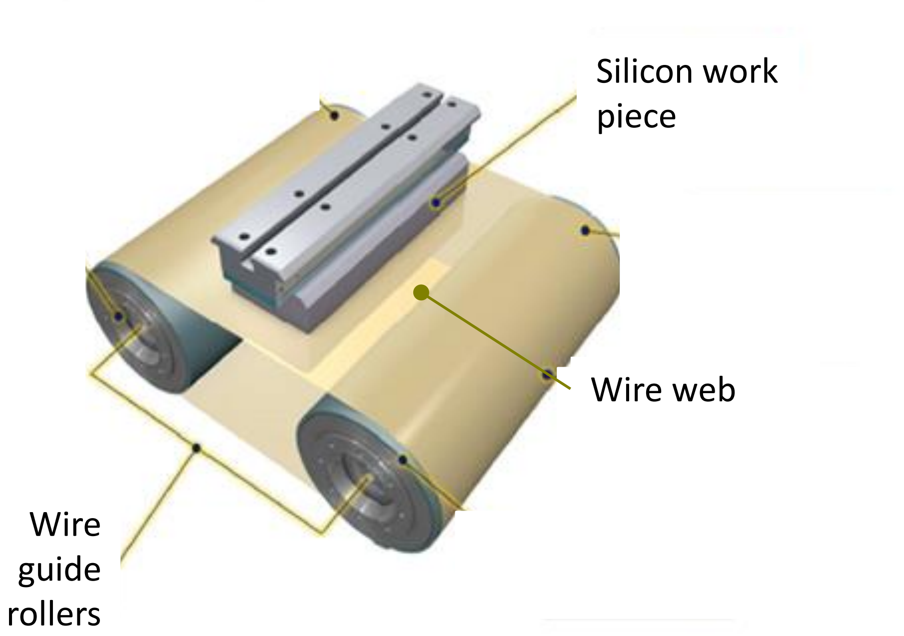
- Crucible diameter should exceed ideally 3-times ingot diameter
- If crucible is too small:
  - Influence of crystal rotation will have stronger impact on melt flow and stability
  - Variations in crucible diameter will be impacting growth much more severely
  - Pull speed increases with crucible/ingot diameter ratio
- Larger crucibles => stronger natural convection in the melt => less stability => more structure losses
- Larger diameter means more loss for every structure loss (length of one diameter lost).
- Some limitation to get the latent heat out along the ingot radius + thermal stresses, which may limit the pull speed.
- (Can't compare directly with 300 mm semicon ingots because they have very different pullers with superconducting magnets.)

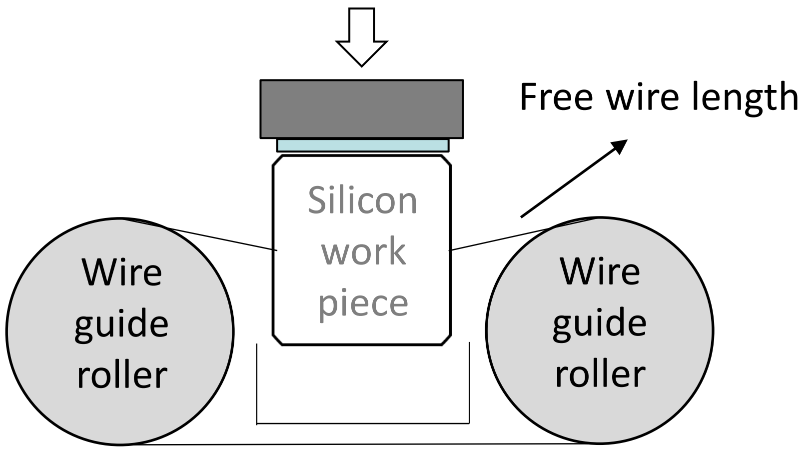




Fundamental **challenges** of larger wafers in wafer production

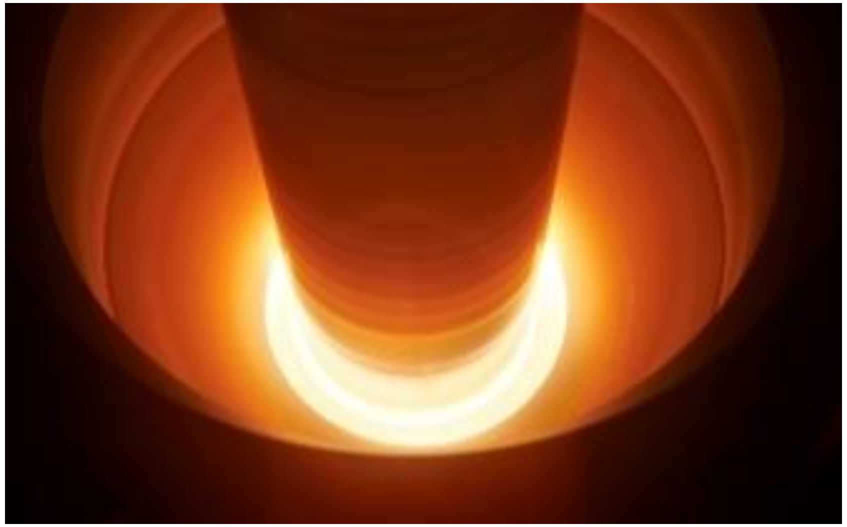
- Saws require larger distance between wire guide rollers to accommodate larger blocks/wafers in between
  - => Reduced stability as longer unsupported wire length
  - => May need to increase wire tension to maintain stable cutting
  - => May need to increase core wire thickness, i.e. higher kerf loss and hence fewer wafers per ingot block
  - => lower throughput and higher cost (potentially large effect)
- Wafer yield typically 0.5-1% reduced with M10/G12 compared to M6, larger impact per area or Wp (significant cost effect)
  - Higher breakage
  - More prone to stains (longer cutting channel, hard to wash out kerf during high-speed DW slicing)
  - Higher Total Thickness Variation (TTV)?
- Wafer thickness
  - Have to increase wafer thickness when going larger? That would mean higher cost (large effect).





Are larger wafers better?

- For ingot and wafer production the gains are limited as several factors compensate each other
- Production process control and yield are critical
- Potential for greater gains with focus on thinner wafers instead, in particular for high-efficiency technologies such as heterojunction and IBC, to reduce polysilicon cost per Wp
- Larger wafers *per se* are not necessarily significantly better or cheaper (per Wp)
- Cost reduction potential in terms of LCOE seems to be greatest in optimizing the whole system including efficiency, system configuration and design, transport and BOS
- Bankability?



It simply feels good to use hydropower to produce solar cell materials