2nd International Workshop on CIGS Solar Cell Technology,
April 12-14, 2011

# GW Production in Solar Frontier K.K. : Current Status and Future Prospect

**Katsumi Kushiya**
Solar Frontier K.K.
(and Showa Shell Sekiyu K.K.)

# Sincere appreciation

**Sincere appreciation for your warm encouragement and strong support to Japan, especially the people in Tohoku District, who had sudden change of the life.**
**We would not be beaten by the current tough situation until the ordinary life is back to us.**

# Outline

- Current Status
- Future Prospect
- Conclusions

# Showa Shell Sekiyu Group

Head Office: Daiba Frontier Building
In Tokyo

**Showa Shell Sekiyu K.K.**

Oil Refining and Domestic Sales

| Saudi Aramco | Royal Dutch Shell | General Stockholders |
|---|---|---|
| 15% | 35% | 50% |

**100% Subsidiary,**
**Solar-PV related Business: Manufacturing and Sales**

**Solar Frontier K.K.**

100%

**Solar Frontier Europe, GmbH**

100%

**Solar Frontier Americas, Inc.**

# Showa Shell Sekiyu K.K. with Solar-PV

1978: Start the R&D of Solar-PV system with single crystal Si PV modules.

1988: Kushiya started the CIS research as a visiting researcher of the R&D team in ARCO Solar, Inc.
1993: Start the NEDO PV R&D projects on the development of CIS-based thin-film PV technology.

2005: Make a decision on the commercialization with CIS-based thin-film PV technology.
2006: Establish the Showa Shell Solar K.K.
2007: Start the commercial production of CIS-based thin-film PV modules with 20 MW/a in Miyazaki.
2009: Open the Atsugi Research Center.
2010: Change the company name to Solar Frontier K.K.

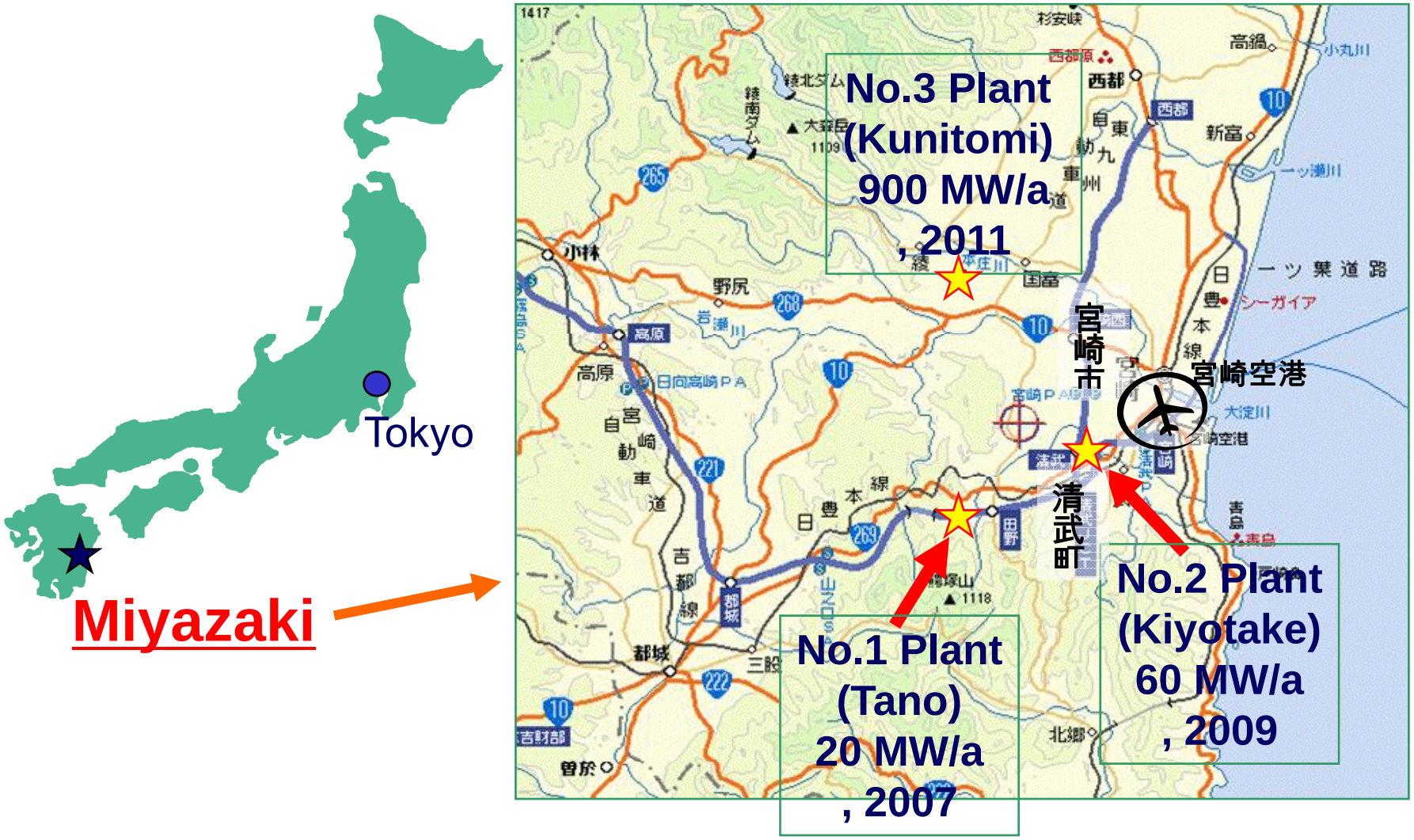
2011: Will start the mass-production of CIS-based thin-film PV modules in the 3rd plant of 900 MW/a, which means Solar Frontier will be a company with one GW/a production capacity.

# Target of Showa Shell Sekiyu K.K.

- **It was done to be a company with two energy sources, *oil and Solar-PV.***

- **It will be on the way to be a company on the net profit by FY-2014, 50 billion yen by Oil business and 50 billion yen by Solar-PV business.**

# CIS Plant Location



# Production Capacity

Solar Frontier K.K. is the company exclusively manufacturing the CIS-based thin-film PV modules with a ***Cd-free*** **$Zn(O,S,OH)_x$** buffer layer.

**20 MW/a Plant**

No.1 Plant (Tano)
Start up: October 2006

**60 MW/a Plant**

No. 2 Plant (Kiyotake)
Start up: November 2008

**900 MW/a Plant**

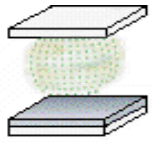
No. 3 Plant (Kunitomi)
Start up: February 2011 (No.1 Line), March 2011 (No.2 Line)

Home page: http://www.solar-frontier.com/

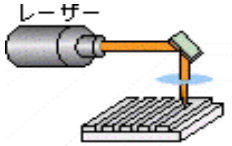
***Full operation will be started by mid-2011.***

# Baseline Process

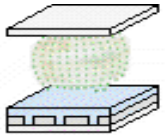
Substrate preparation
<Glass Wash>



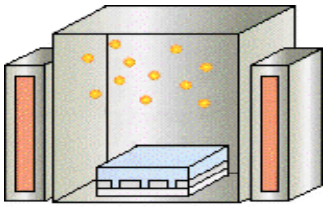
Metal Base Electrode
<DC Magnetron Sputtering>



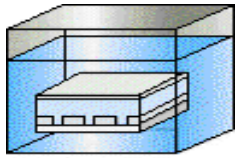

Pattern 1
<Laser Scribing>



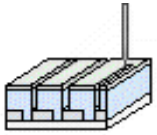
Metal Precursor
<DC Magnetron Sputtering>



p-type CIS-based Absorber
<**Sulfurization after Selenization**>



High-resistivity **$Zn(O,S,OH)_x$** Buffer
<Chemical-bath Deposition>



Pattern 2
<Mechanical Scribing>

n-type BZO Window
<**MOCVD**>

Pattern 3
<Mechanical Scribing>

Finishing

Packaging: Same technology as Crystalline-Si solar cells

# Device Structure

| Company | p type Absorber | n type layers | Substrate |
|---|---|---|---|
| Würth Solar | Coevaporation $CIGSe_2$ | CBD-CdS Sputtering-AZO | Glass |
| Solibro | | | |
| Global Solar Energy | | | Stainless steel foil |
| **Solar Frontier** | **SAS** **$CIGSe_2$ with $CIG(Se,S)_2$ Surface layer** | **$CBD\text{-}Zn(O,S,OH)_x$** **MOCVD-BZO** | Glass |
| Bosch Solar CISTech | SAS $CIG(Se,S)_2$ | CBD-CdS Sputtering-AZO | |
| AVANCIS | RTP-Simultaneous Selenization&Sulfurization $CIG(Se,S)_2$ | CBD-CdS Sputtering-AZO | |
| Honda Soltec | Selenization $CIGSe_2$ | **$CBD\text{-}In(S,OH)_x$** Sputtering-AZO | |

# Better position of SAS process

| Better position | Reasons |
|---|---|
| Since highly reactive gas can be used, drastic reduction of Se consumption is possible. | Required Se amount is estimated at about 1/40 of solid Se case. (Excellent materials saving) |
| Metal precursor layers can be prepared by DC magnetron sputtering, which is a proven technology on the excellent thickness control and high rate deposition. As the result, thinner CIS-based absorber is possible in a controlled thickness range of 1.2 to 1.5 micron. | CIS-based absorber thickness in the commercialization is estimated as at least 0.5 micron thinner than Coevaporated ones. (Excellent materials saving) |
| End-of-life sputtering targets can be recycled, because of no contamination. | Sputtering targets are in the recycle flow. (Excellent materials saving and cost reduction) |
| 60cmx120cm size is a current standard, but Solar Frontier K.K. will use a 90cmx120cm size substrate in the 900 MW production. | *Substrate size will be larger than CdTe, but smaller than a-Si.* |

# Substrate Size

## R&D in the NEDO Solar-PV R&D Projects

Single cell with Top grids → Monolithically Integrated Circuit

$1cm^2$ →
***Test Structure***: $3.2cm^2$
(16 cells) on 10cmx10cm ($100cm^2$)

$50cm^2$ on $100cm^2$ → $80cm^2$ on $100cm^2$
→ 10cmx30cm ($300cm^2$)
→ 30cmx30cm (1footx1foot, $900cm^2$)
→ 30cmx120cm (1footx4feet, $3,600cm^2$)

**20 MW/a Plant** → **60 MW/a Plant**

60cmx120cm

(2feetx4feet, $7,200cm^2$)

**900 MW/a Plant**

90cmx120cm

(3feetx4feet, $10,800cm^2$)

# Improvement of Output: Reality

| Period | Rated Power [$W_p$] on **Catalogue** base | Miyazaki Plant |
|---|---|---|
| From Apr., 2007 To Apr., 2009 | 70 75 **w/ JET, TUV & UL** **2x4 size** | No.1 |
| **From Sep., 2009 To Today** | **80 85** **90** Export only | No.2 |
| ***From Apr., 2011*** | **3x4 size** **130 140** **w/ JET, TUV & UL** | No.3 |

***150W is coming soon.***

# Marketing Segments

Mega Solar: 1 Mega Solar-PV Power System in Miyazaki **No.2 Plant**

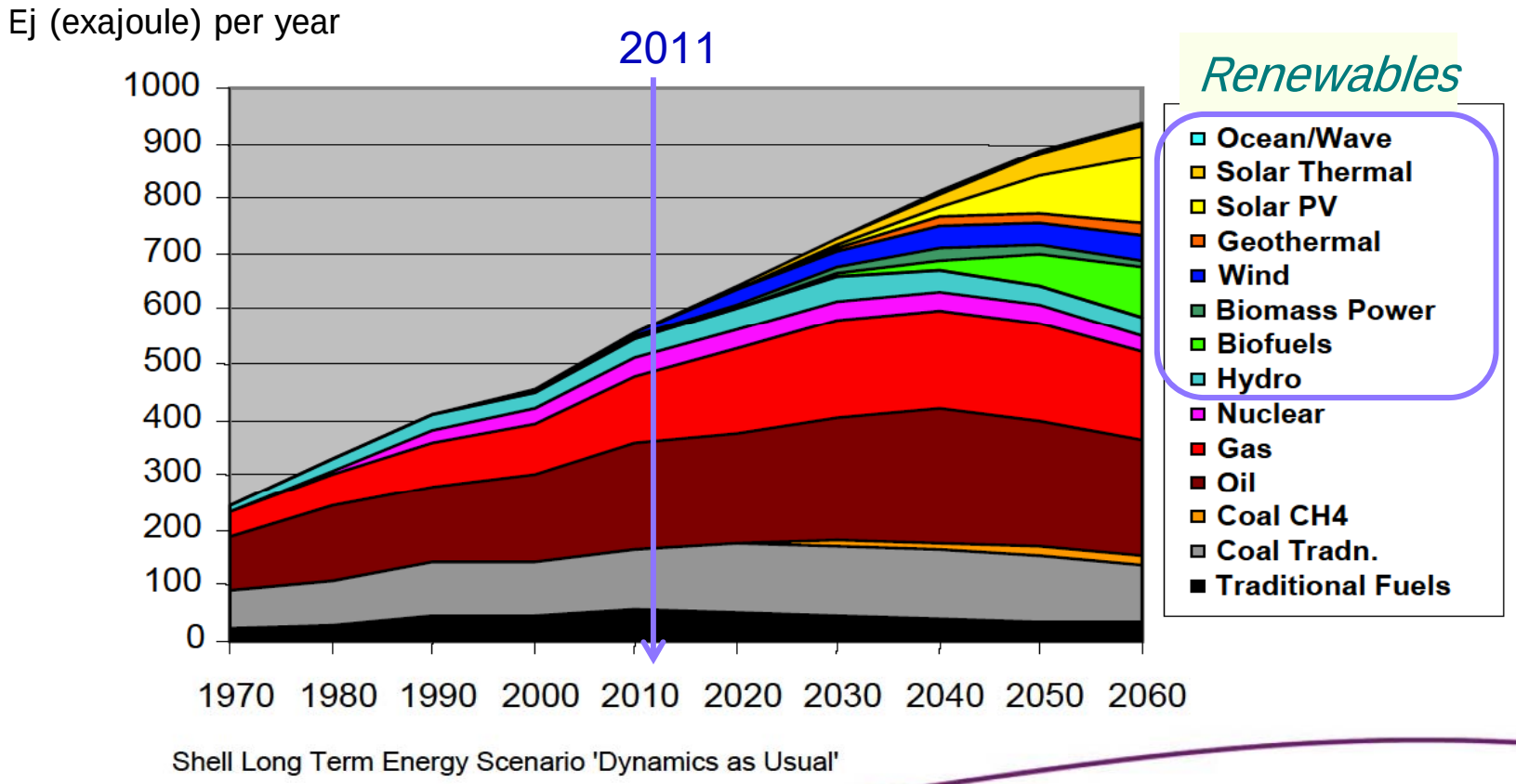
Roof-top Application in Japan

# Outline

- Current Status
- **Future Prospect**
- **Conclusions**

# Toward the Energy mix era: (*Trend of global primary energy demand)*

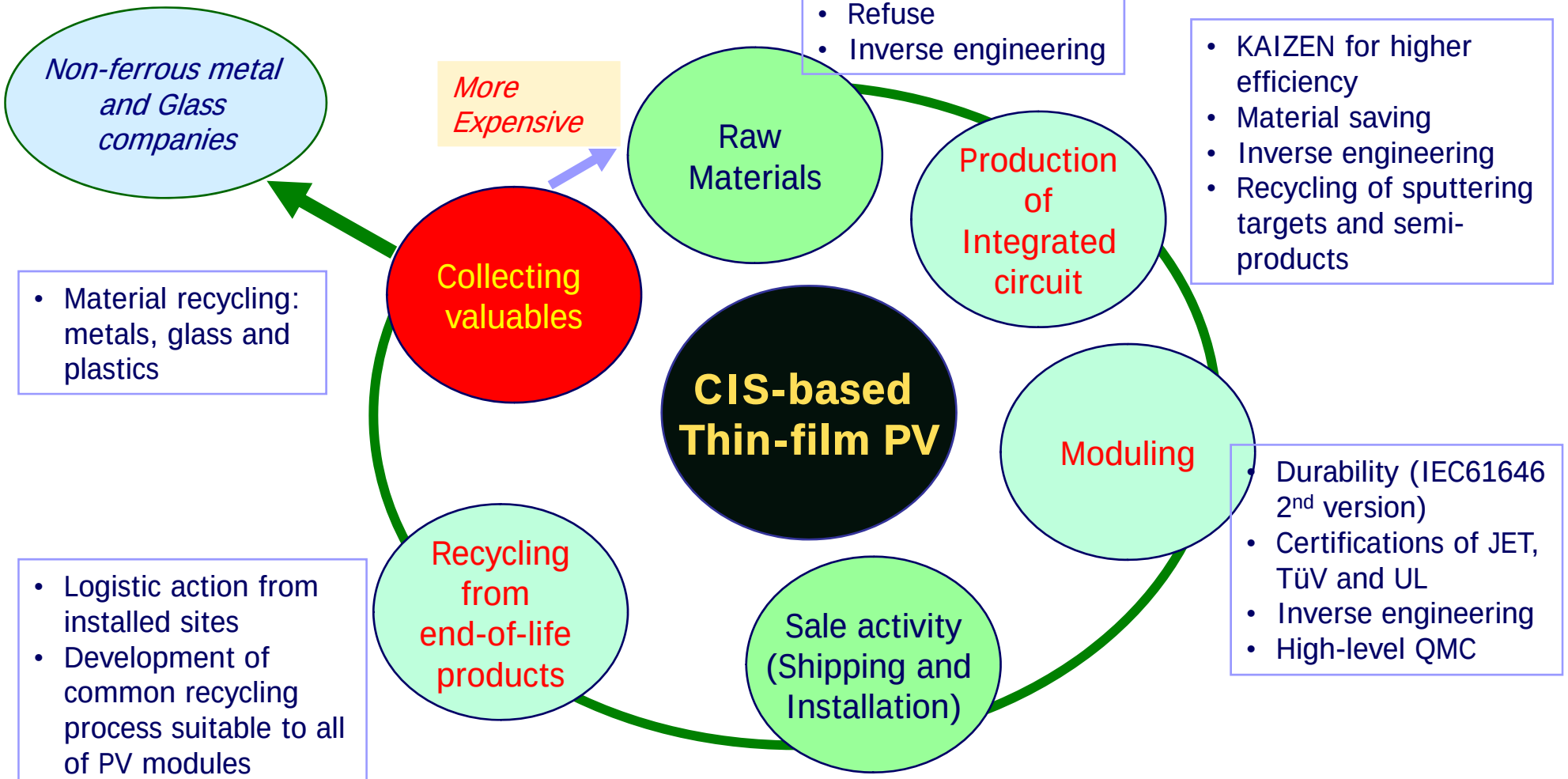
## Shell's long term scenario – a transition to renewables




Shell Long Term Energy Scenario 'Dynamics as Usual'

Shell Renewables

# Total Product Lifecycle-Chain Control




- Refuse
- Inverse engineering

- KAIZEN for higher efficiency
- Material saving
- Inverse engineering
- Recycling of sputtering targets and semi-products

- Material recycling: metals, glass and plastics

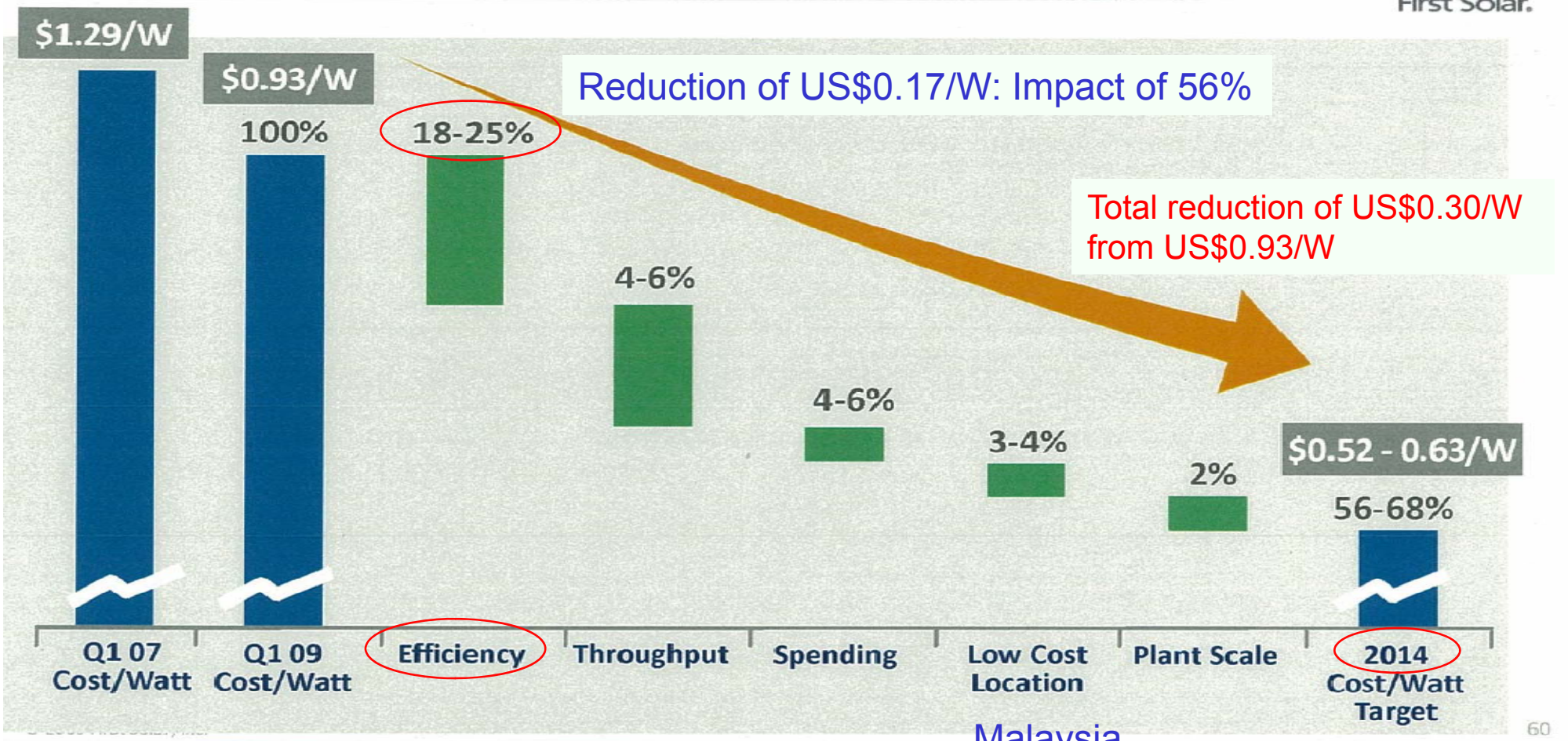
- Durability (IEC61646 2nd version)
- Certifications of JET, TüV and UL
- Inverse engineering
- High-level QMC

- Logistic action from installed sites
- Development of common recycling process suitable to all of PV modules

- No restriction on installation
- Customer satisfaction
- Good communication with customers

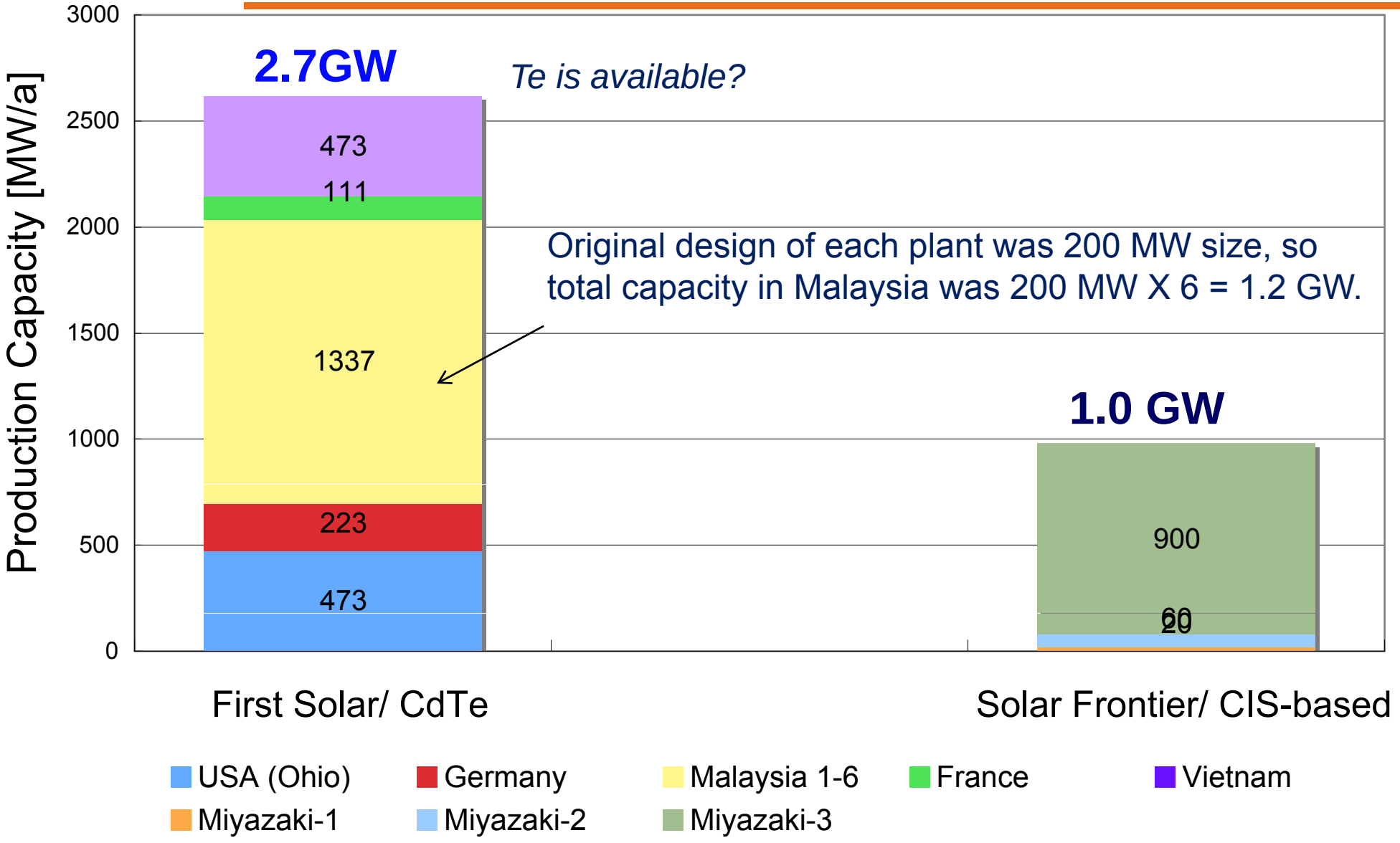
# First Solar, Price Leader

**Their basic understanding is it is necessary to improve the efficiency for mfg cost down.**




Malaysia

# Production Capacity in 2012



# World-record efficiency

| Size | CIS-based/ Glass substrate | CdTe/ Glass substrate |
|---|---|---|
| Small-area single cell (Total-area) | • 20.0 % (0.419cm$^2$) Oct. 2007<br>• 19.4 % (0.994cm$^2$) Jul. 2008<br>Achieved by NREL, CdS buffer<br><br>• 20.3 % (0.5cm$^2$) Aug. 2010<br>Achieved by ZSW, CdS buffer | • 16.7 % (1.032cm$^2$) Sep. 2001<br>Achieved by NREL<br>(Main researchers left the NREL started up the venture company, PrimeStar Solar, which was invested by GE.) |
| Large-area (Over 800 cm$^2$) module (Aperture-area) | • 14.2 % (6840cm$^2$) Jun. 2010<br>Achieved by Solibro, CdS buffer<br><br>•15.7% (9703cm$^2$) Nov. 2010<br>Achieved by Miasole, CdS buffer<br><br>• 13.5 % (3459cm$^2$) Aug. 2002<br>•17.2 % (819cm$^2$) Mar. 2011<br>Achieved by Showa Shell Sekiyu, **$Zn(O,S,OH)_x$ buffer** | • 10.9 % (4874cm$^2$) Apr. 2000<br>Achieved by BP Solarex, who trashed their CdTe technology later. |

Source: Solar Cell Efficiency Tables (Ver.37), Prog. Photovolt: Res. Appl. 2010 and Press Releases.

# Champion Efficiency

Goal for Current NEDO Project is **18%** on 900cm$^2$ (1x1), which would be translated into **16%** on 10,800cm$^2$ (3x4).

| Aperture Area [cm$^2$] | Efficiency [%] | Output [$W_p$] | *Measured by* |
|---|---|---|---|
| 819 | 17.2 * + | 14.1 | *Showa Shell* |
| 839 | 16.3 * + | 13.9 | Showa Shell |
| 815 | 15.8 * + | 12.9 | AIST |
| 3,456 | 13.6 * + | 47.0 | *Showa Shell* |
| 3,459 | 13.5 * + Certified World Record/ Cd free | 46.9 | NREL |
| 7,128 | 13.1 ** | 93.1 | AIST |

* Submodule, + NEDO Solar-PV R&D projects),** Module sourced from the production line of Solar Frontier's Miyazaki 20 MW/a plant.

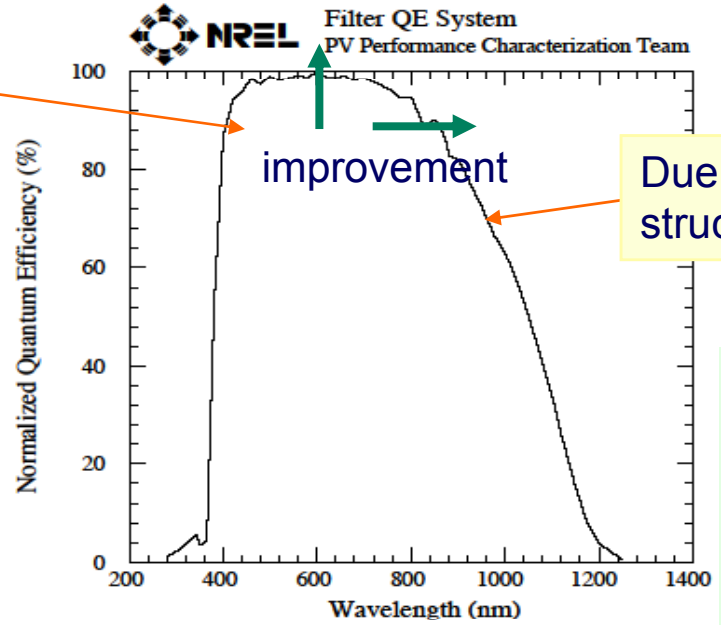
# To improve the quality

**Showa Shell**

**Zn(O,S,OH)x buffer/Cu(InGa)(SSe)2 module**

Device ID: 8M-381
Sep 13, 2001 12:03 PM

Device Temperature: 25.0 ± 1 °C
Device Area: 856.8 cm²




Voltage Bias: 0.0 V
Light bias for 23.6 mA
Light Bias region area: 49.00 cm²
Light Bias Density: 0.4810 mA/cm²

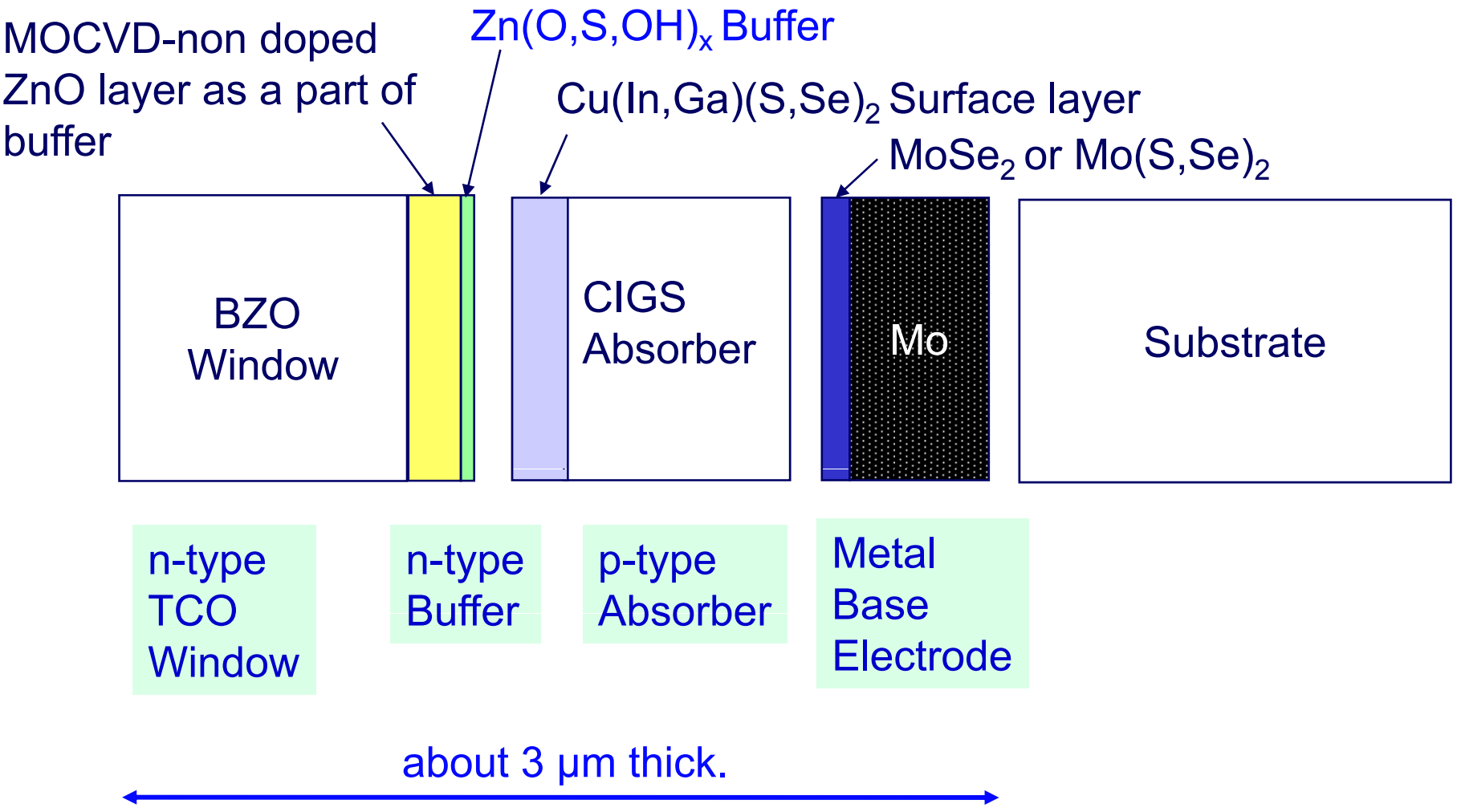
similar to 13.4% module 8N8486198240

Due to the wide-gap $Zn(O,S,OH)_x$ buffer

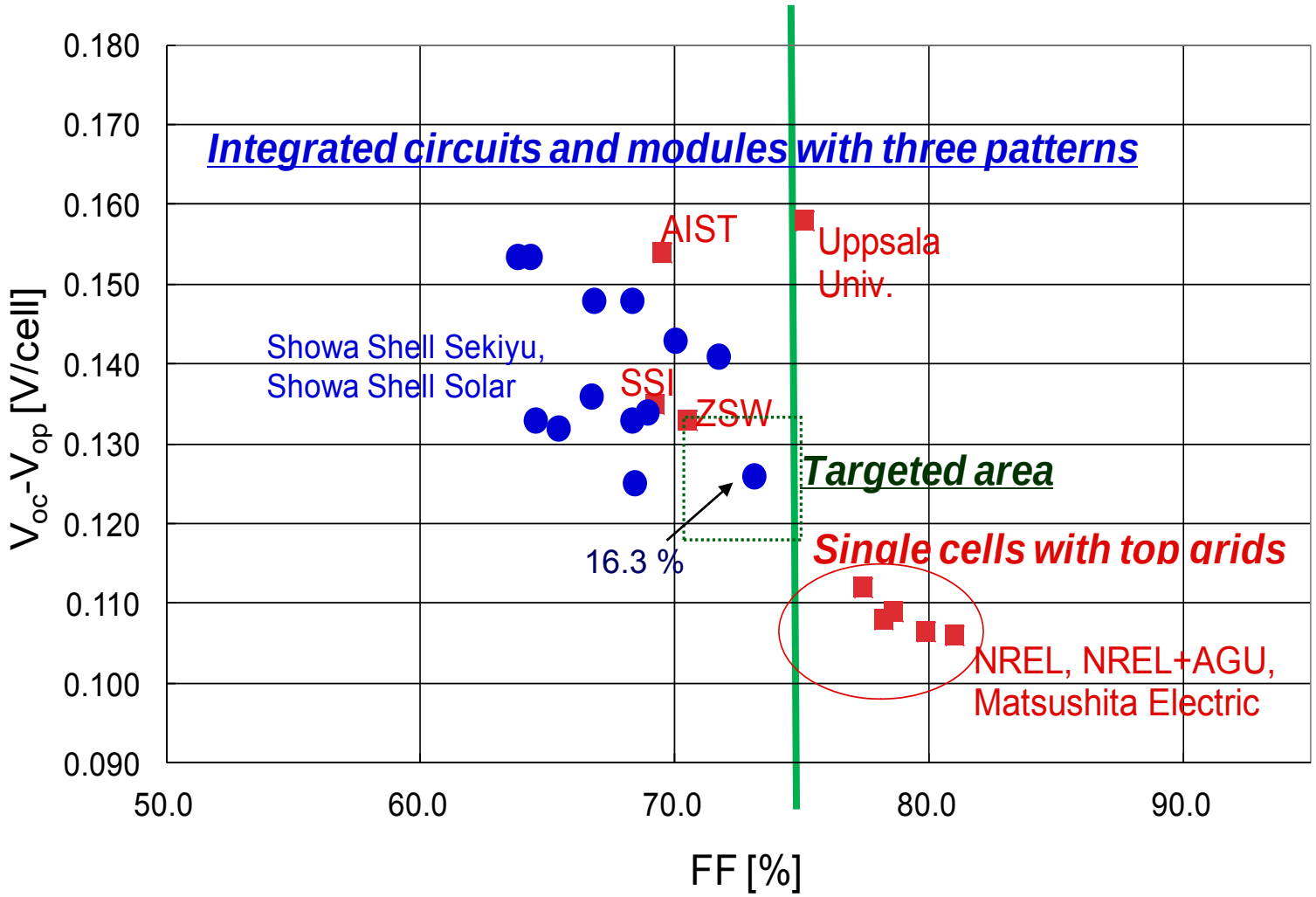
Due to the graded band-gap structure of CIS-based absorber

1)Improve the quality of CIS-based absorber.
2)Reduce the dead area related to the patterning.
3)Improve the quality of pn hetero-junction.
4)Improve the mobility of TCO window layer.

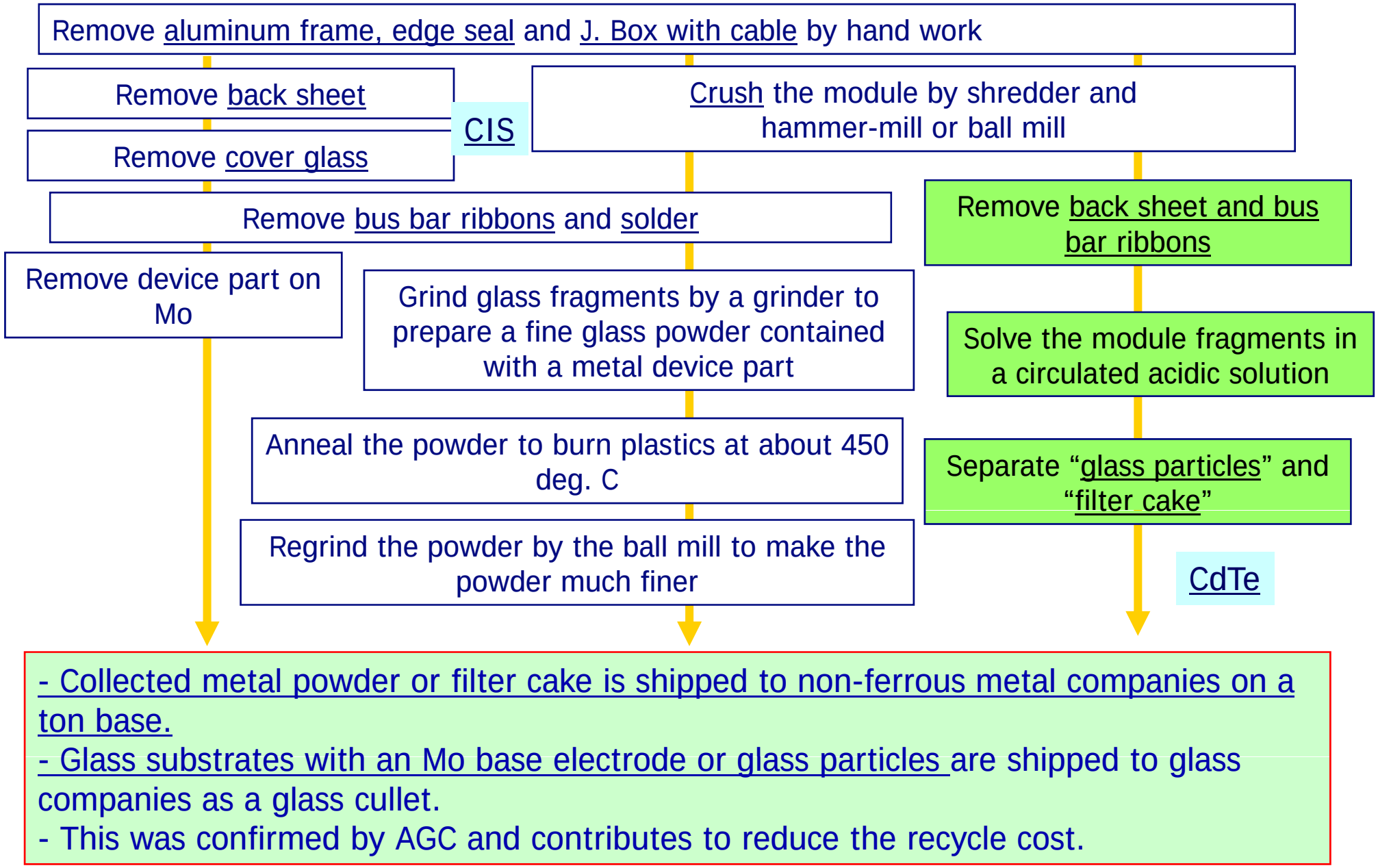
# Device Structure



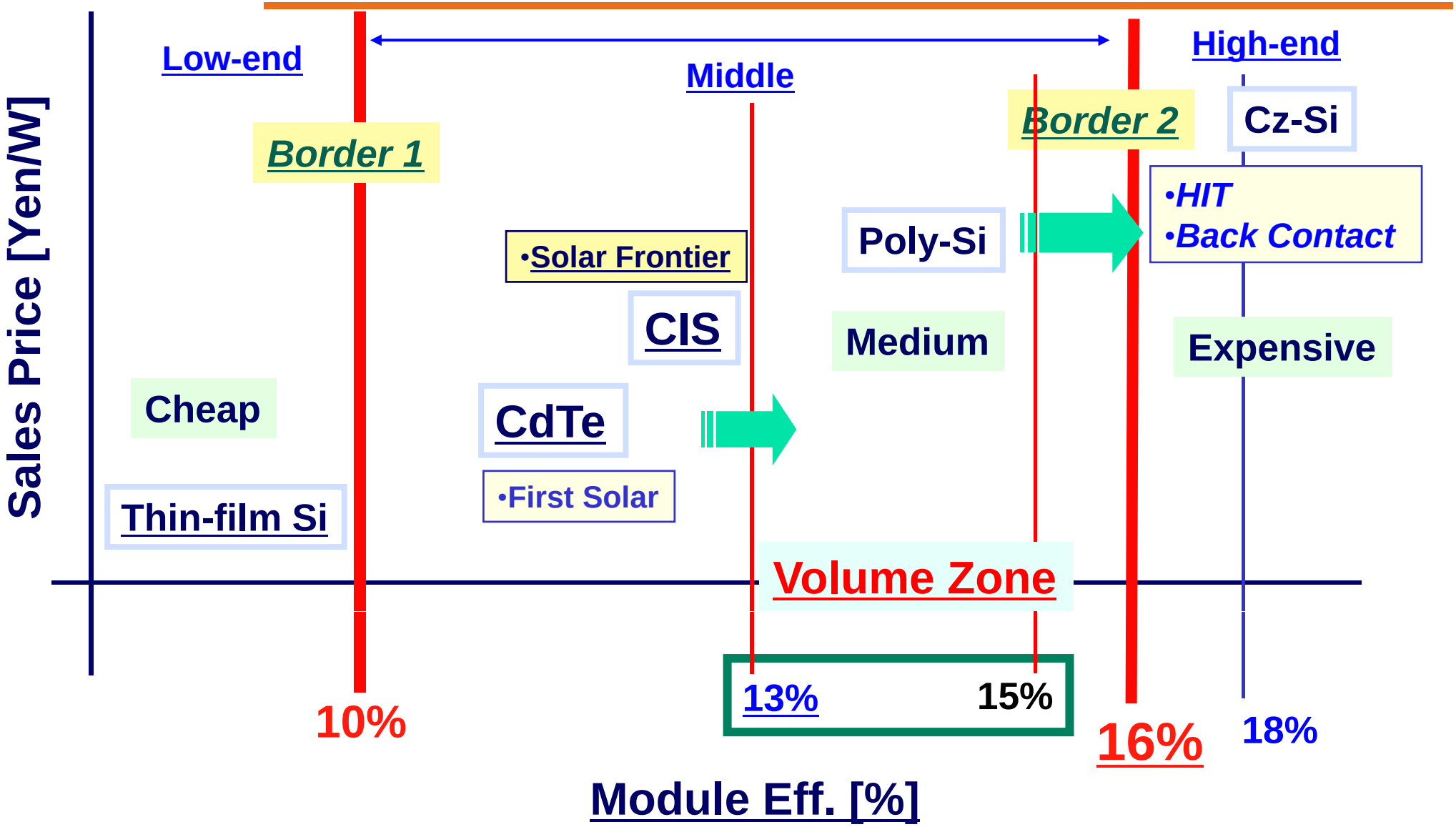
# FF vs. ($V_{oc}$-$V_{op}$) [V/cell]



# Recycle process (Patent pending)



# PV Market: Three Zones



# Conclusion: Our Challenge

What we should do is

1) to improve the module efficiency in the commercial production.
2) to achieve the 18% efficiency on a 900cm$^2$-sized substrate in the R&D activities.
3) to transfer the R&D technology to the commercial production quickly and smoothly.