

The ITRS as a model for a PV roadmap

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All roadmaps are wrong – some roadmaps are useful

- Discussion items
 - A bit of roadmap history
 - Roadmapping and innovation
 - The International Roadmap for Semiconductors (ITRS)
 - PV – the parallel universe
 - Example materials challenges
 - Straw man



Roadmap(ping) history

- Developed and first used in the 1970s by Motorola
- By 1980 - in common use by Motorola, TI, Intel and Japanese firms such as Hitachi and Toshiba

Early Motorola product roadmap

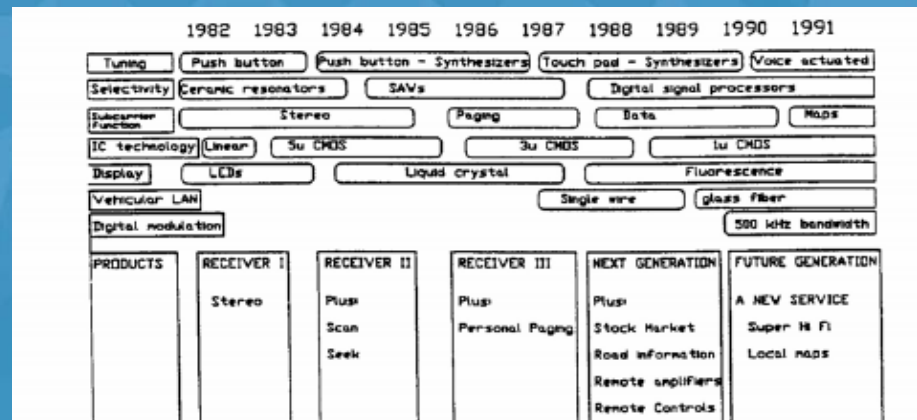
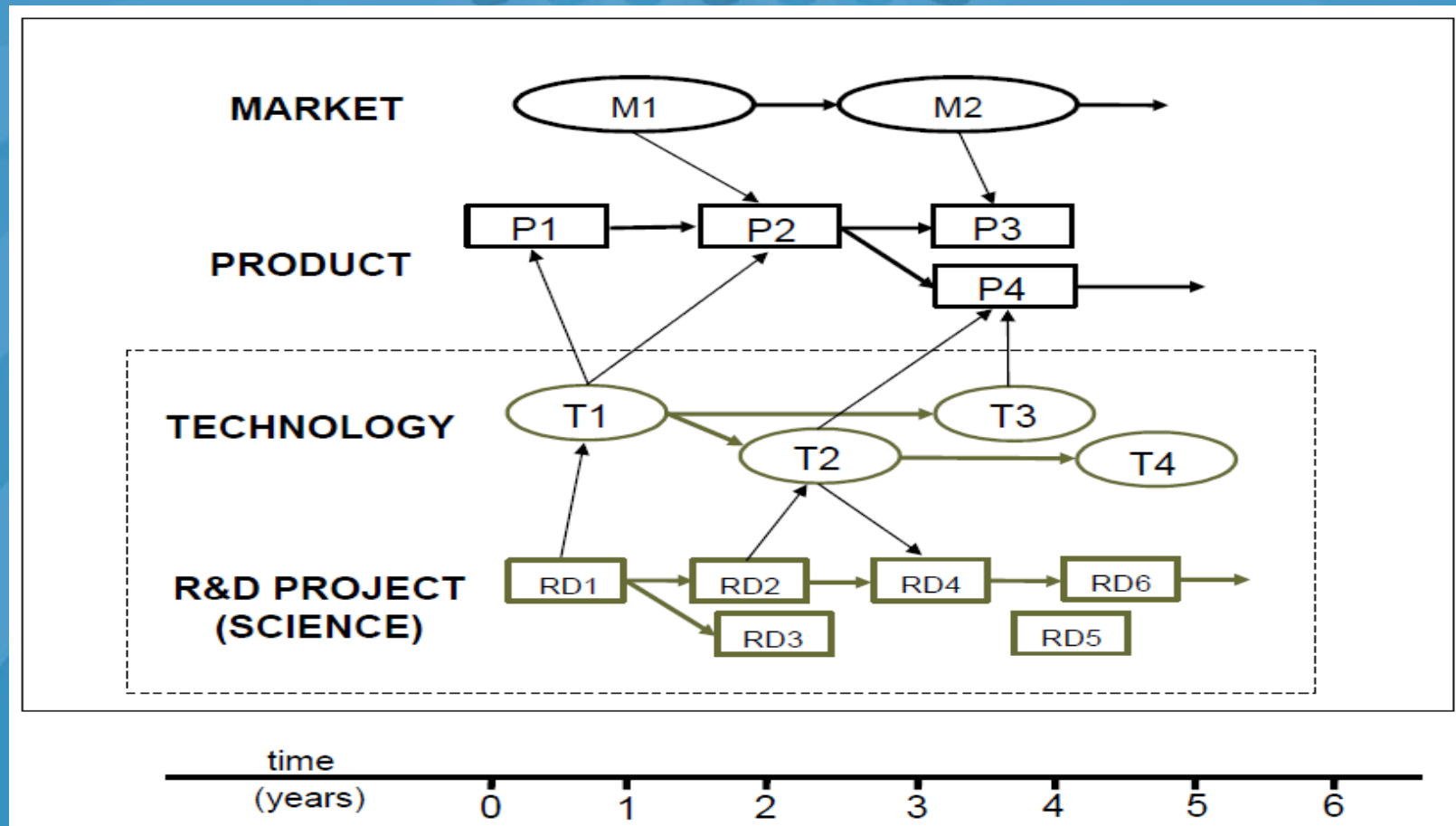


Figure 7.—Technology Roadmap Matrix summarizes technological requirements for future products. This example is for a broadcast automotive FM receiver.

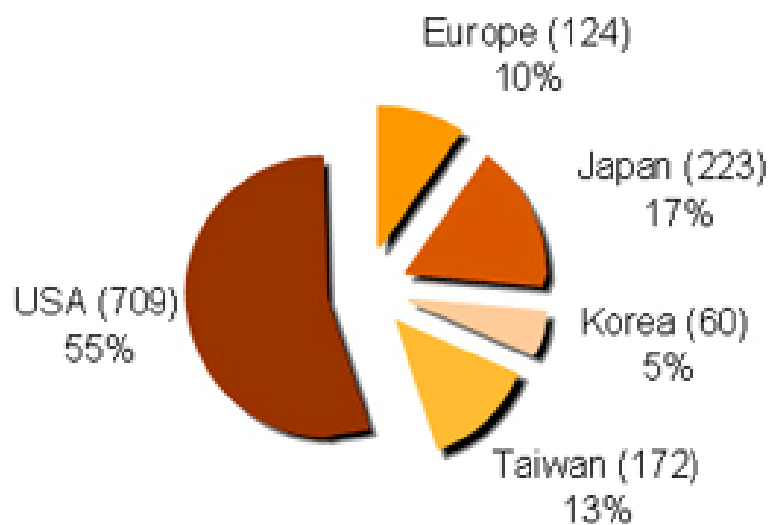
Generic roadmap



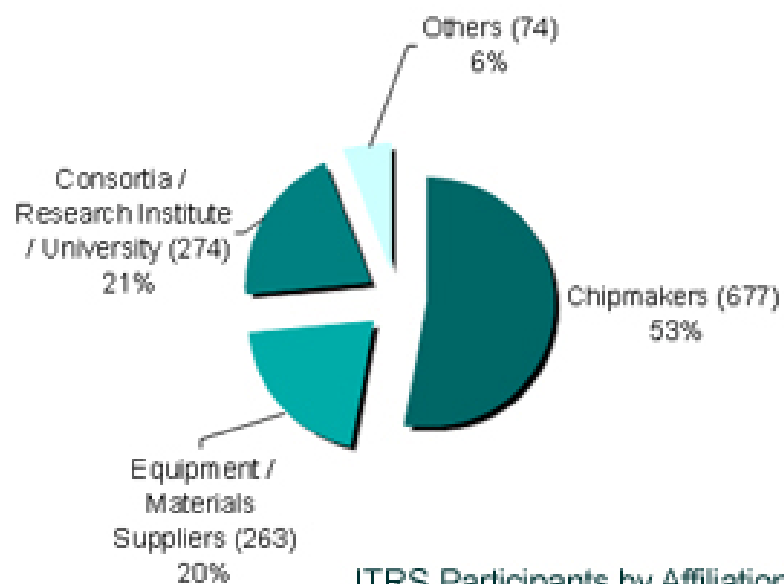
The ITRS sponsors and objective

- Sponsored by the five leading chip manufacturing regions:
 - Europe, Japan, Korea, Taiwan, and the United States
- Objective:
 - ensure cost-effective advancements in the performance of the integrated circuit and the products that employ such devices, continuing the health and success of the industry

ITRS participation demographics



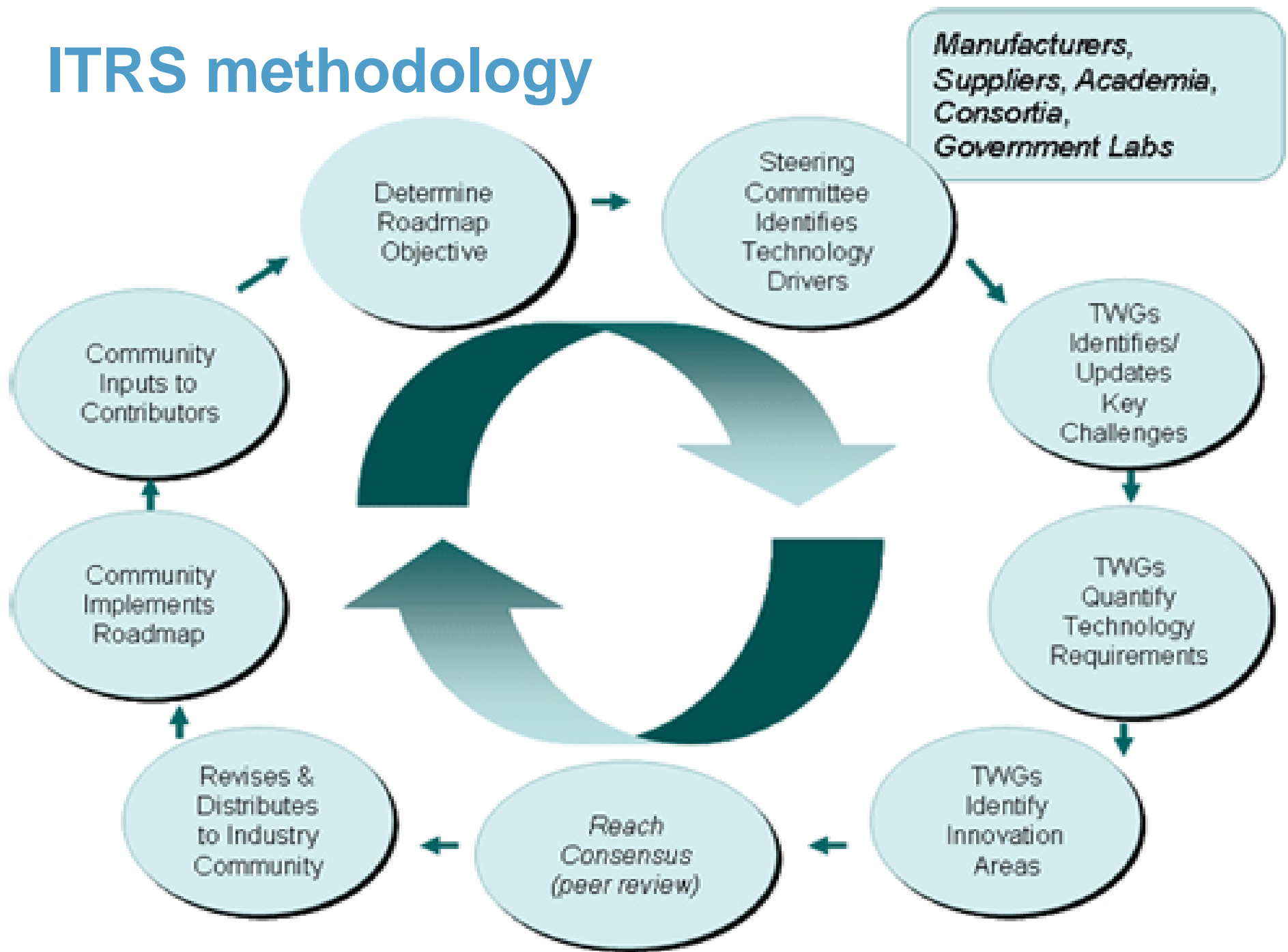
ITRS Participants by Region



ITRS Participants by Affiliation

Over 1300 volunteer participants

ITRS methodology



2008 Barrier/Nucleation/Resistivity

<i>Year of Production</i>	<i>2007</i>	<i>2008</i>	<i>2009</i>	<i>2010</i>	<i>2011</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>
<i>MPU/ASIC Metal 1 1/2 Pitch (nm)(contacted)</i>	68	59	52	45	40	36	32	28	25
Barrier cladding thickness Metal 1 (nm)	4.8	4.3	3.7	3.3	2.9	2.6	2.4	2.1	1.9
Conductor effective resistivity ($\mu\Omega$-cm) Cu Metal 1	3.51	3.63	3.8	4.08	4.30	4.53	4.83	5.2	5.58

<i>Year of Production</i>	<i>2016</i>	<i>2017</i>	<i>2018</i>	<i>2019</i>	<i>2020</i>	<i>2021</i>	<i>2022</i>
<i>MPU/ASIC Metal 1 1/2 Pitch (nm)(contacted)</i>	22	20	18	16	14	13	11
Barrier cladding thickness Metal 1 (nm)	1.7	1.5	1.3	1.2	1.1	1.0	0.9
Conductor effective resistivity ($\mu\Omega$-cm) Cu Metal 1	6.01	6.33	6.7	7.34	8.19	8.51	9.84

- ALD barrier processes and metal capping layers for Cu are lagging in introduction
- Resistivity increases due to scattering and impact of liners
 - No known practical solutions



ITRS Roadmap challenges

- Overcoming “red brick wall”
- Path dependency: how to balance on-and off-roadmap innovation
- Caution of becoming too unwieldy and prescriptive
- “Roadmap” may not be the best metaphor - implies certainty
- Maintaining voluntary participation
- Increasing cost of roadmapping
- Tends to emphasize incremental innovation
- Participation mix between suppliers and regions mixed

Why is the roadmap successful?

- Roadmap has adapted and evolved along with the industry it serves.
 - Driven by common purpose
 - Technology specific but adaptable
- Process is public
 - Collaborative
 - Organised
- Strong industry commitment ensures that it is kept up-to-date and reflects the most complete collective knowledge of technology needs.
- Healthy “beat-the-Roadmap” competitive behavior helps reinforce success.
- Evolves with the industry – now includes ESH and emerging materials

Semiconductor innovation

- ITRS roadmap emerged from the recognition that the productivity curve, known as Moore's Law could only be maintained with sustained technology efforts
- Often offered as a model or template for other roadmap efforts
- Semiconductor technology innovation is usually characterized as being evolutionary
- Roadmapping serves this type of organized innovation well
- Collecting a great amount of knowledge in great amount of detail

PV – the parallel universe

- Similar technology age
- Crystalline and thin film improvements evolutionary
- Productivity enhancements from tool suppliers and automation
- 20% + CAGR
- Consortia and university technology pipeline
- Many analogous trends

Roadmaps – success and opportunity

- Semiconductor – success, roadmap driven
- Flat panel displays – success, no roadmap, leveraged learning from semiconductor
- MEMS – sufficient, not roadmap driven
- Solid state lighting – entering scaling phase which will challenge suppliers
- Printable electronics - entering scaling phase which will challenge suppliers

Where can we adapt existing learning and standards to PV?

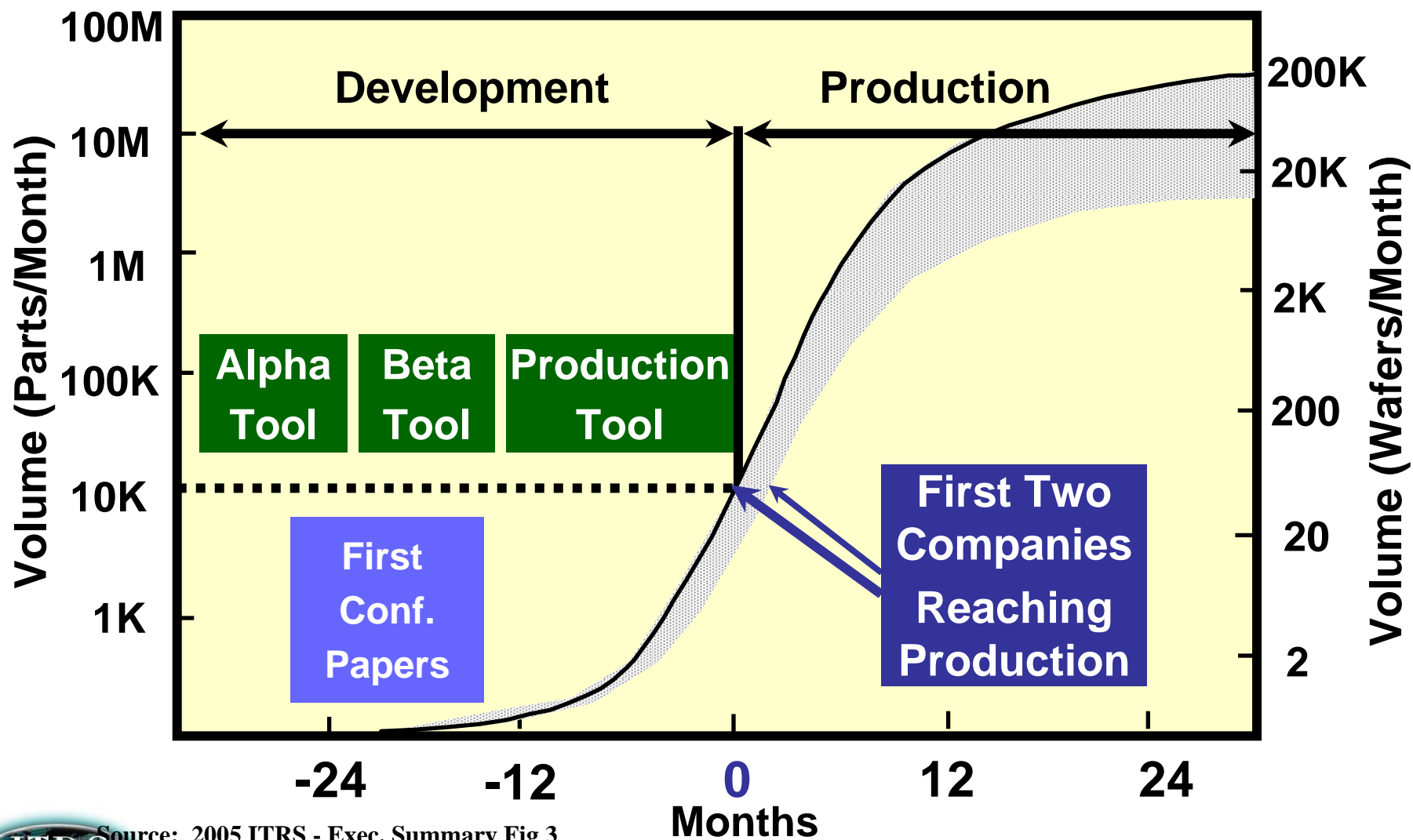
Some PV Roadmap Opportunities

- Bulk solar cell fabrication or thin film PV cell fabrication
 - Chemical and gas general specifications
 - Defect specifications
 - Purity specifications
 - Chemical hazards
 - Utilization
- Silicon and polysilicon supply
- Wafer manufacturing and slicing specifications
- Substrate and cover glass specifications
 - TCO
- Module assembly and balance of systems

Fig 3

2008 - Unchanged

Production Ramp-up Model and Technology **Cycle Timing**



Source: 2005 ITRS - Exec. Summary Fig 3

Summary

- To ensure
 - lowest cost per watt
 - availability and security of supply
 - safety
 - best usage of industry resources
- Roadmap technical specifications including
 - Purity
 - Substrate specifications
 - utilization per wafer/substrate
 - delivery and packaging technology
 - new material requirements for TCO
 - ESH standards
 - sustainability metrics – GWP potential, manufacturing energy



All roadmaps are wrong

a PV roadmap would be useful