Nano-to-Life Expert Survey Results

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at Tel-Aviv University

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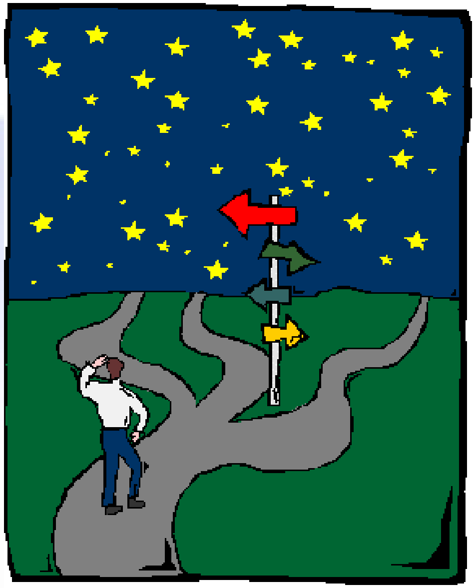
Objectives of the expert survey



- Validate selected trends emerged from the SoA review
- Insight on R&D priorities, taking into account opinions of a large group of specialists.
- Identify consensus (or disagreement) on key issues relevant to the long-range development of NBT
- Input for Roadmapping → Strategy

ICTAF

Nano2Life

Structure of the expert survey

20 statements: anticipated application-oriented developments in NBT

Expert opinion requested on:

- ***Year of realization***
- ***Impact on 4 domains***
- ***Prospects of commercialization in 5 areas***
- ***What limits the prospects of commercialization***
- ***Actions needed (to increase likelihood)***

Selection of topics

Based on…

SoA review

Core experts suggestions

Compromise:

Cover entire field – limited numb
topics

Desired detail – length, time…

General data

First draft of questions – Dec 2004

Pilot – Jan-Feb 2005   Munster comments – March 05

Design & test of the web-based questionnaire – March – Apr 05

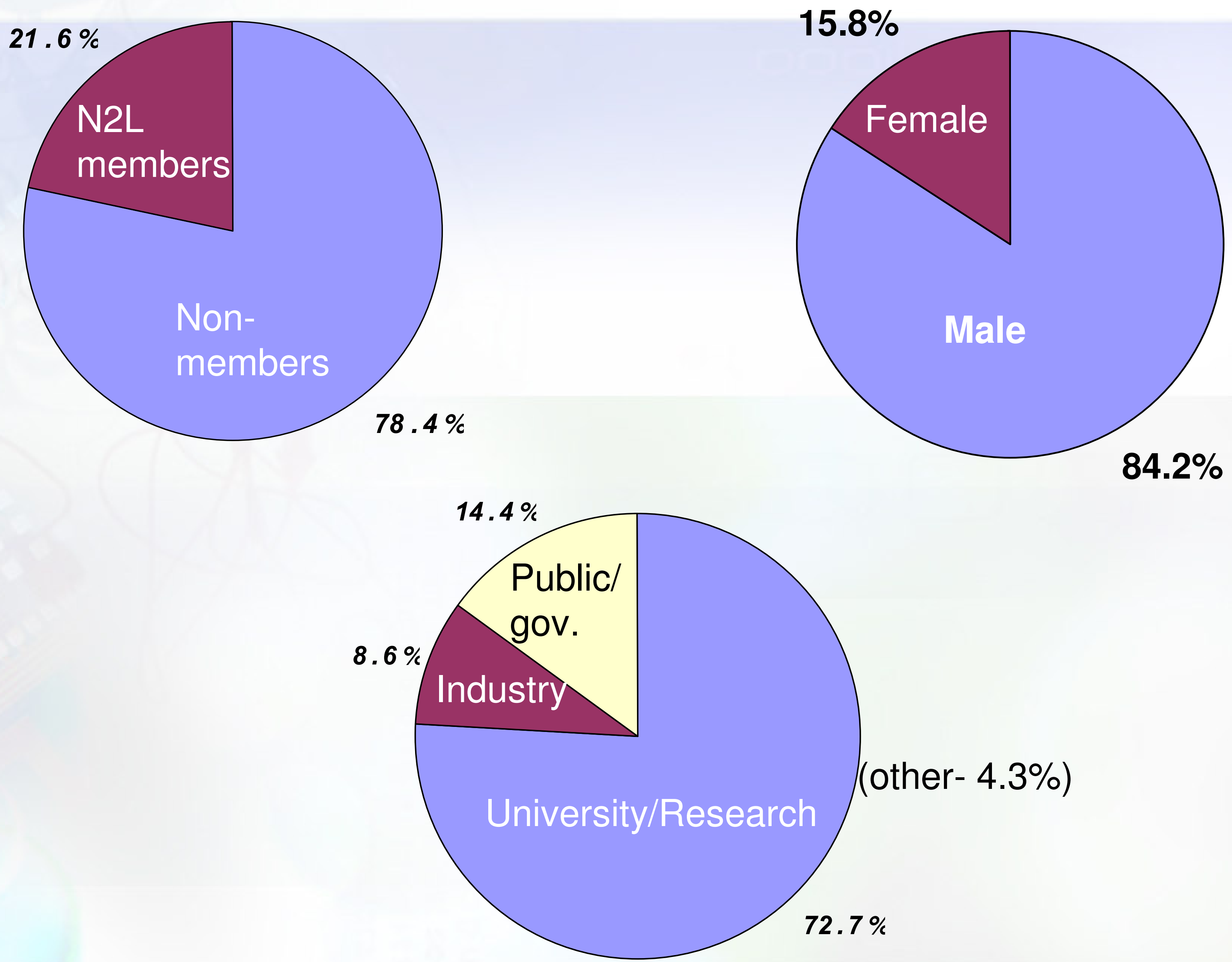
Online survey start: 17.4.05   end: July 2005

139 respondents   (**30** N2L members   **109** non-members)

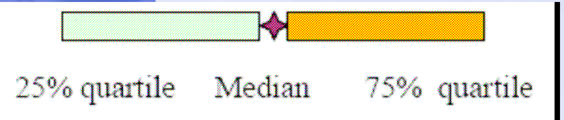
22-79 responses per statement

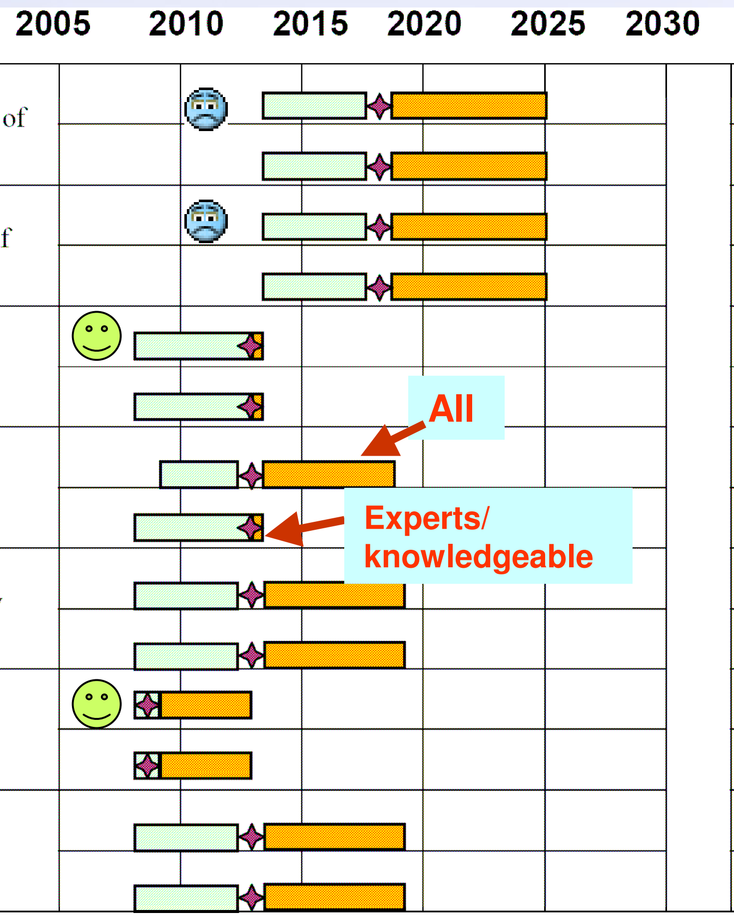
30 countries

Respondents distribution (139)



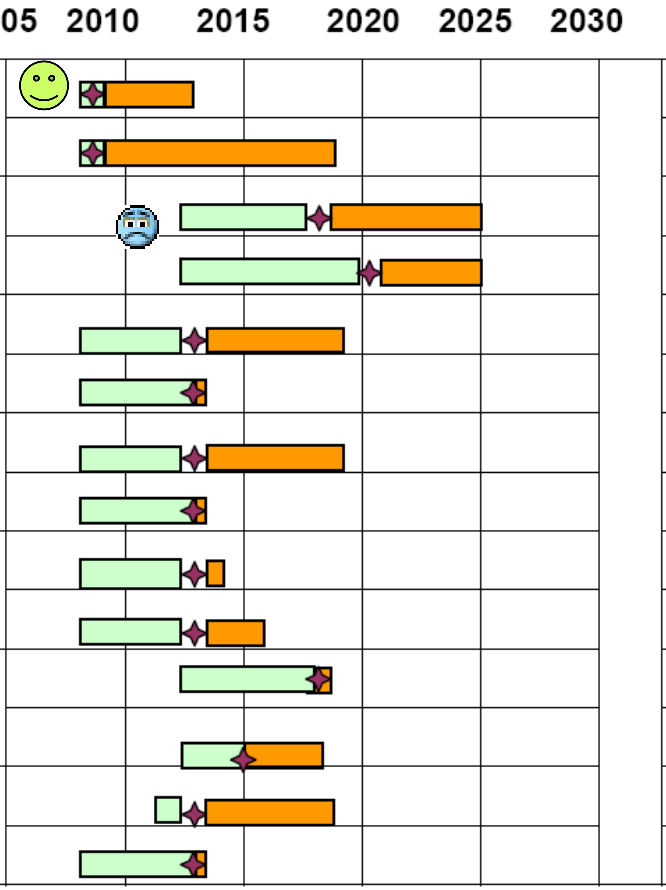
Time of realisation – all statements





Statement	N	"Never"
1. Cellular cycle Thanks to advances in nanobiotechnology, the fundamental processes of the cellular cycle are mostly understood	79	7.6 %
	46	6.5%
2. In vitro construction of human organs Advancements in nanobiotechnology enable the construction in vitro of artificial human organs.	51	7.8%
	25	8.0%
3. Nanostructured biomaterials Novel nanostructured biomaterials replace existing materials (e.g. polymers).	64	10.9%
	46	13%
4. Targeted drug delivery Targeted drug delivery based on nanoparticles becomes a standard tool (for therapeutic purposes, performance enhancement etc).	73	1.4%
	49	2.0%
5. Smart probes used in in-vivo Smart probes (that illuminate when reaching their target) are practically used in diagnosis in-vivo.	40	5.0%
	22	0%
6. Biodetection with smart nano-surfaces Smart and adaptable surfaces at the nanoscale are the basic building block for Biodetection.	52	0%
	38	0%
7. Nanotools for manipulation inside cells Nanotools (e.g. optical tweezers) are used for manipulation inside cells while keeping the cells' integrity and activity.	39	12.8%
	19	5.3%

Time of realisation – all statements (cont.)



Statement	N	"Never"
8. Nano-agents for analysis inside cells Nanosized imaging agents (e.g. quantum dots) are used for analysis and diagnosis inside cells without affecting their normal functionality.	51	5.9%
	30	0%
9. Bio energy conversion in micro/nano systems Biological energy conversion systems (e.g. biomolecular motors) are practically used in artificial micro and nano systems.	33	12.1%
	18	11.1%
10. Bio-inspired materials Advanced bio-engineered materials based on bio-inspiration/ bio-mimicry are widely used.	36	0%
	20	0%
11. Labs on chip Labs on chip are widely used for various applications, in different sectors, including households.	46	0%
	31	0%
12. Protein & DNA chips integrated Protein chips are integrated with DNA chips for specific diagnosis purposes in current hospital practices.	31	0%
	24	0%
13. Protein chips for personal use Protein chips are widely used by the public for personal use.	31	25.8%
	22	18.2%
14. Cells on chips replace animal testing In vitro tests based on cells on chips replace animal testing for various applications (e.g. pharma, cosmetics…).	32	18.8%
	20	20%

Time of realisation – all statements (cont.)

Statement	N	"Never"
15. Biosensors for single molecules Biosensors for detection of single molecules based on nano arrays (for example, arrays of nanotubes) are commercially available.	42	4.8%
	31	6.5%
16. Self-assembly widely implemented Self-assembly is widely implemented as a technique for development of materials and devices.	47	4.3%
	38	0%
17. Self-repairing in artificial systems Living self-repairing abilities are implemented in artificial systems.	22	22.7%
	10	20.0%
18. Nanomachines inside the body Nano-machines for theranostics (therapy and diagnosis) are practically used inside the body.	35	11.4%
	19	15.8
19. Chips employing biomolecules Chips employing biomolecules as active elements are commercially manufactured.	39	5.1%
	20	5.0%
20. Chips made by using DNA / peptides Nanoelectronics chips are commercially manufactured by using DNA or peptides (as templates or for nanopatterning).	34	5.9%
	19	0%

Classification by likely time-frames

Short term – before 2010:

6. Biodetection with smart adaptable nanosurfaces
8. Nano-agents for analysis inside cells

Medium term –2011- 2015:

3. Nanostructured biomaterials.
4. Targeted drug delivery.
5. Smart probes used in-vivo
7. Nanotools for manipulation inside cells
10. Bio-inspired materials
11. Labs on chip
12. Protein chips integrated with DNA chips
14. Cells on chips replace animal testing
15. Biosensors for single molecules
16. Self-assembly.
19. Chips employing biomolecules as active elements
20. Chips commercially manufactured by using DNA or peptides

Classification by likely time-frames (cont.)

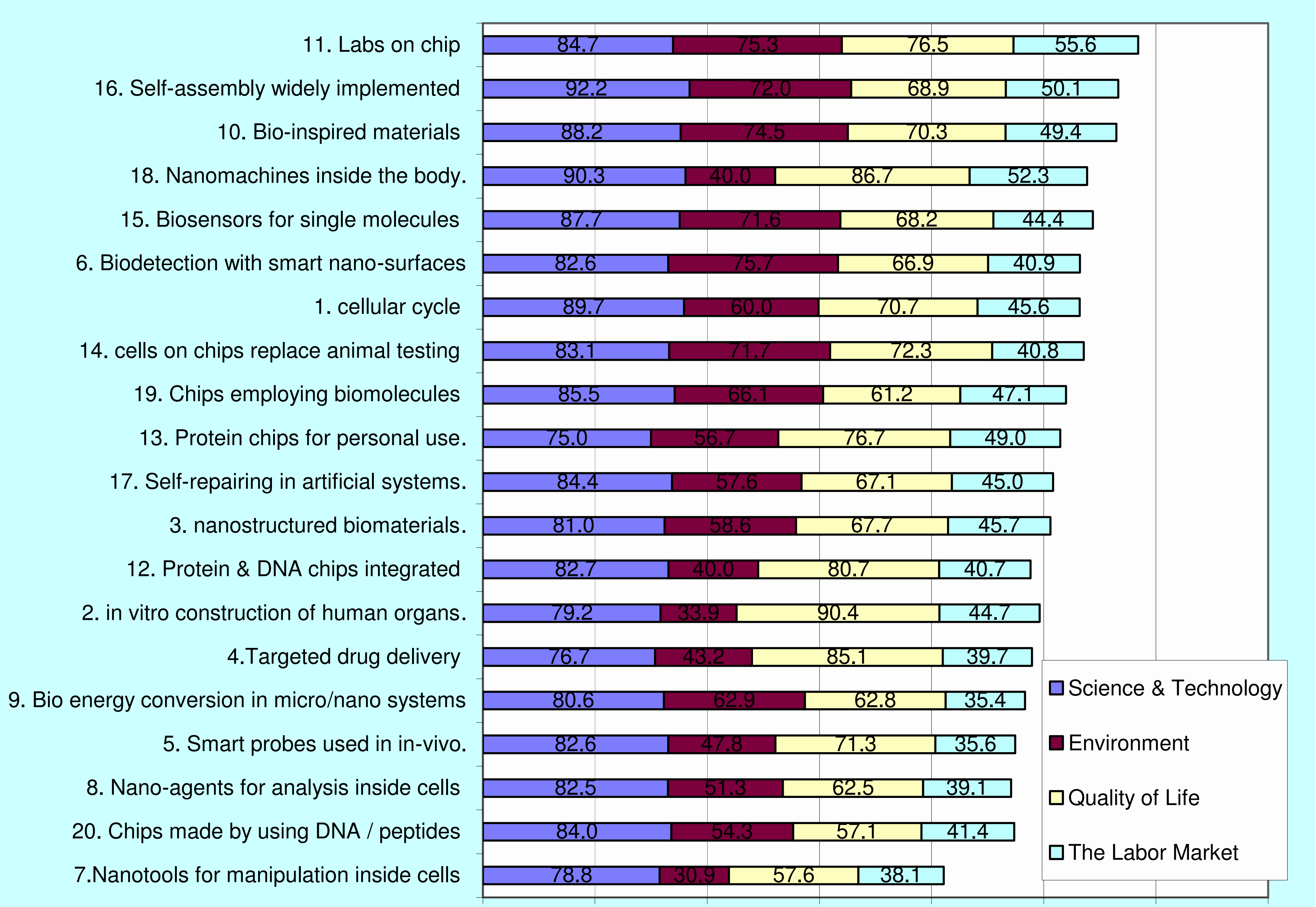
Long term –2016- 2020:

1. Thanks to NBT, processes of the cellular cycle are mostly understood
2. Construction in vitro of artificial human organs.
9. Bio energy conversion practically used in micro/nano systems
13. Protein chips for personal use
17. Living self-repairing implemented in artificial systems

Very long term – 2021-2025:

18. Theranostic nano-machines used inside the body

Impact levels on four domains (ranked by overall impact)



Highest overall impact (71-73%):

11- **Labs on chip**, 16- **Self-assembly**, 10- **Bio-inspired materials**.

Highest impact on S&T (> 89%):

16- **Self-assembly,** 18- **Nanomachines in the body,**
1- **Understanding cellular cycle**.

Highest impact on environment (>74%):

11- **Labs on chip,** 10- **Bio-inspired materials**,
6- **Biodetection with smart nano-surfaces**.

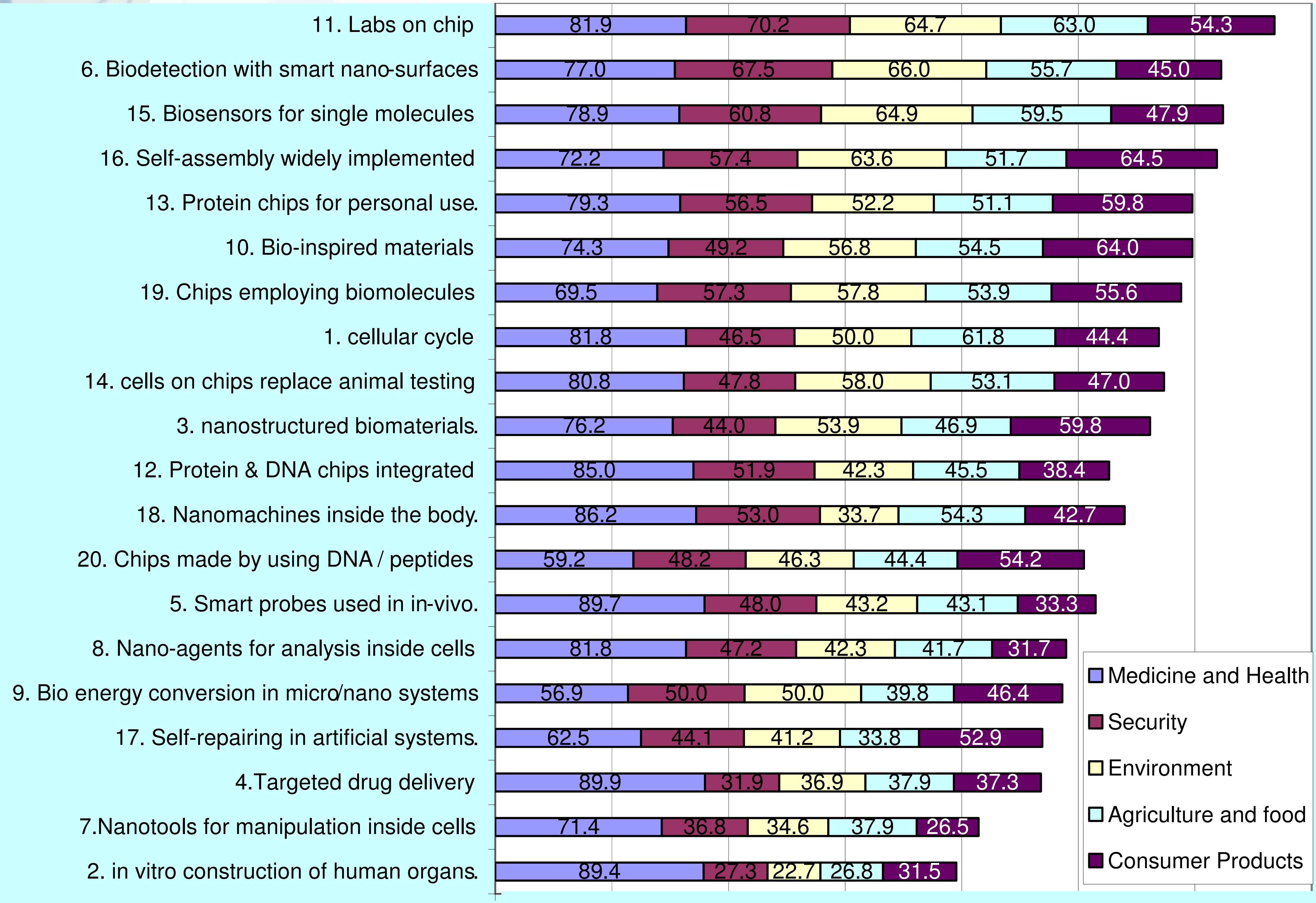
Highest impact on quality of life (> 80%):

2- in vitro construction of human organs, 12-**Protein & DNA chips integrated**, 18- **Nanomachines in the body**.

Impact on **labor market** generally low. **Highest (> 50%):**

11-**Labs on chip**, 16- **Self-assembly,** 18- **Nanomachines in the body**.

Commercialisation prospects in 5 application areas



Topics with highest prospects of commercialisation:

Highest overall prospects (> 62%):

11- lab on chip, 6-biodetection, 15-biosensors

Highest prospects are in **Medicine & Health (> 89%,** 9 topics >80%)

4-Targeted drug delivery, 2- in vitro construction of human organs, 5-Smart probes used in in-vivo

Security & Environment (>60%):

11- lab on chip, 6-biodetection, 15-biosensors.

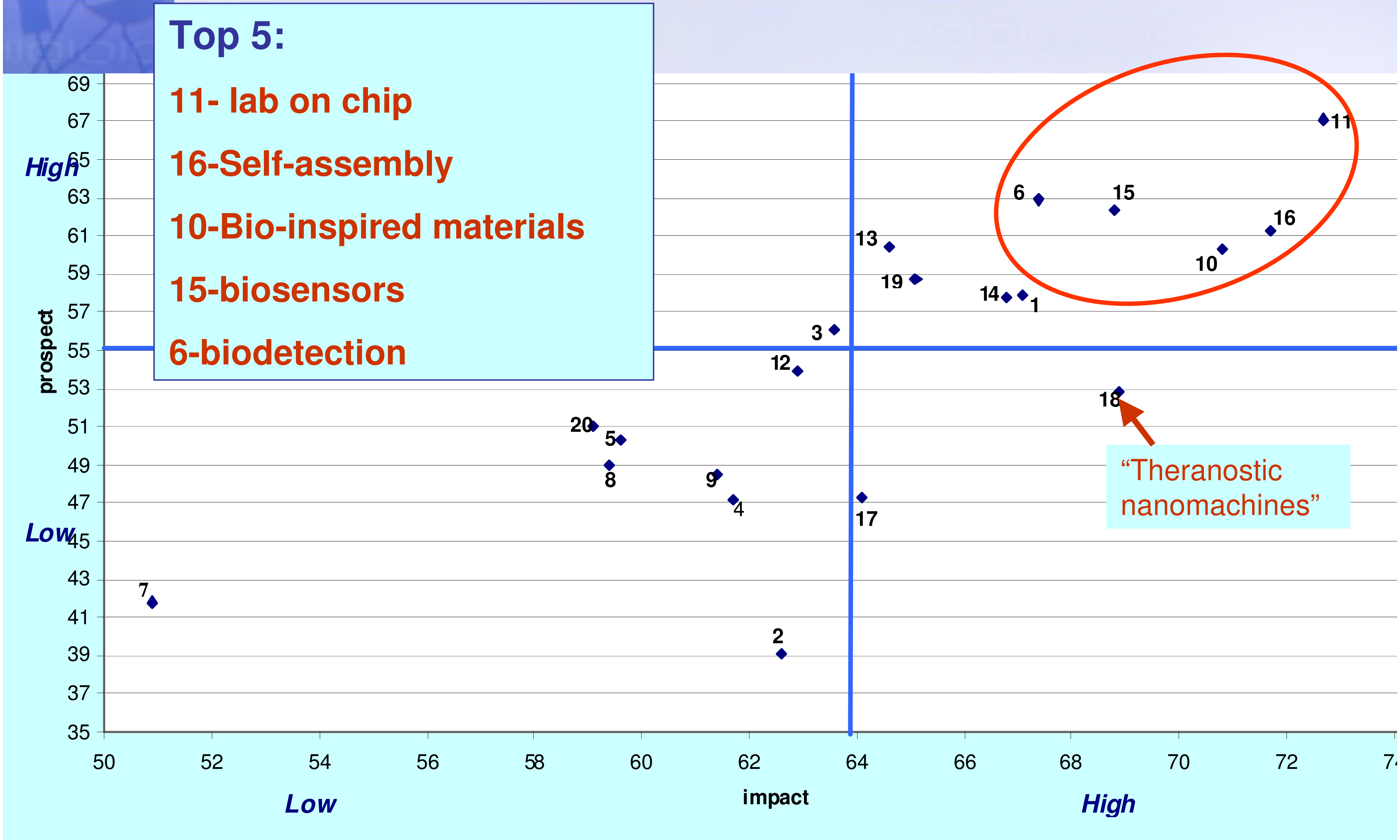
Agro-Food (>60%):

11- lab on chip, 1- Understanding cellular cycle, 15-biosensors

Consumer products (>60%):

16-Self-assembly widely implemented, 10-Bio-inspired materials, 13-Protein chips for personal use, 3-Nanostructured biomaterials

Overall impacts & prospects



Percentage of “nothing limits” in all areas

(top 3 highlighted in each area)

statement	Medicine & Health	Security	Environment	Agro-food	Consumer Products
1. cellular cycle	35.9	27.6	34.5	28.8	26.3
2. in vitro construction of human organs.	22.0	11.1	8.6	11.8	20.0
3. nanostructured biomaterials.	44.2	29.2	40.4	31.8	**40.4**
4.Targeted drug delivery	42.1	18.0	16.3	23.4	24.4
5. Smart probes used in in-vivo.	39.4	26.7	30.0	35.7	22.2
6. Biodetection with smart nano-surfaces	**51.2**	**57.5**	**57.9**	**51.4**	**42.9**
Nanotools for manipulation inside cells	29.6	20.0	16.0	12.5	9.1
. Nano-agents for analysis inside cells	40.5	29.0	34.4	26.7	25.9
. Bio energy conversion in micro/nano ystems	21.7	14.3	22.7	22.7	23.8
0. Bio-inspired materials	20.7	29.2	44.4	25.9	37.0
1. Labs on chip	**42.1**	**47.1**	**45.7**	**47.6**	**44.7**
2. Protein & DNA chips integrated	**45.8**	40.0	35.3	42.1	35.0
3. Protein chips for personal use.	26.3	33.3	26.3	26.3	29.4
4. cells on chips replace animal testing	38.9	38.9	40.0	**44.4**	33.3
5. Biosensors for single molecules	24.1	37.0	31.0	27.6	21.4
6. Self-assembly widely implemented	28.6	**45.7**	36.1	31.4	33.3
7. Self-repairing in artificial systems.	21.4	38.5	28.6	35.7	21.4
8. Nanomachines inside the body.	28.6	15.0	5.0	10.0	10.5
9. Chips employing biomolecules	29.2	43.5	**47.8**	43.5	39.1
0. Chips made by using DNA / peptides	14.3	9.5	10.0	10.0	4.6

Limits to commercialization - Medicine & Health (%)
(large levels of disagreement highlighted)

High percentage of "many barriers":

17. Self-repairing in artificial systems (78.6%)

2. in vitro construction of human organs (75.6%)

18. Theranostic nanomachines inside the body (71.4%)

	Nothing limits	Many barriers	Needs already fulfilled	No needs
cellular cycle	35.9	56.3	6.3	1.6
in vitro construction of human organs.	22.0	75.6	2.4	0
nanostructured biomaterials.	44.2	36.5	17.3	1.9
Targeted drug delivery	42.1	50.9	7.0	0
Smart probes used in in-vivo.	39.4	57.6	3.0	0
Biodetection with smart nano-surfaces	51.2	37.2	11.6	0
Nanotools for manipulation inside cells	29.6	63.0	7.4	0
Nano-agents for analysis inside cells	40.5	54.1	5.4	0
Bio energy conversion in micro/nano systems	21.7	60.9	13.0	4.3
). Bio-inspired materials	20.7	51.7	13.8	13.8
1. Labs on chip	42.1	44.7	13.2	0
2. Protein & DNA chips integrated	45.8	45.8	8.3	0
3. Protein chips for personal use.	26.3	52.6	15.8	5.3
4. cells on chips replace animal testing	38.9	44.4	11.1	5.6
5. Biosensors for single molecules	24.1	62.1	10.3	3.4
5. Self-assembly widely implemented	28.6	65.7	2.9	2.9
7. Self-repairing in artificial systems.	21.4	78.6	0	0
3. Nanomachines inside the body.	28.6	71.4	0	0
). Chips employing biomolecules	29.2	58.3	8.3	4.2
). Chips made by using DNA / peptides	14.3	42.9	33.3	9.5

Actions needed to foster realization

- Most needed: increase in basic/applied research
- Least needed: fiscal/financial measures
- Regulation needed mainly in:

Protein&DNA chips (48%), Drug delivery (40%)

- Coping with ethical or public acceptance issues needed especially in (>50%):

In-vitro construction of organs,

Theranostic nanomachines inside the body, and

Living self-repairing abilities in artificial systems.

Significant Disagreements

Time of realisation:

No.	Statement	% Before 2015	% After 2020
1	Understanding cellular cycle	43	30
2	In vitro construction of human organs	37	31
9	Bio-energy conversion in nanosystems	36	33
17	Living self-repairing in artificial systems	32	23
20	Electronic chips made by DNA/peptides	50	35

Highest percentage of "never":

13. Protein chips for personal use (25.8%)

17. Living self-repairing implemented in artificial systems (22.7%)

14. Cells on chips replace animal testing (18.8%)

Significant Disagreements (cont.)

High percentage of "nothing limits" *AND* "many barriers" (same topic), in Medicine & Health:

3. Nanostructured biomaterials (44%, 37%)
4. Targeted drug delivery (42%, 51%)
11. Labs on chip (42%, 45%)
12. Protein & DNA chips integrated (49%, 49%)
14. Cells on chips replace animal testing (39%, 44%)

Conclusions (to be finilised…)

The survey provides a worldwide view on anticipated developments in NBT, their impacts and prospects, emerging from judgments of a large group of NBT experts.

High priority topics (taking into account overall impact & prospects):

- **Labs on chip**
- **Self-assembly**
- **Materials based on bio-inspiration/bio-mimicry**
- **Biosensors for single molecules**
- **Biodetection with smart nano-surfaces**

Highest impact of most statements is on S&T.

Low impact on the labor market

Conclusions (cont.)

Medicine & Health is the area with highest prospects for commercialization: 9 topics scoring more than 80%.

Lower prospects in Security and Environment

In security & environment topics of detection & identification have relatively higher prospects (>60%): lab on chip, biodetection, biosensors

Most statements are likely to be realized in the decade 2010- 2020.

Biodetection with smart nano-surfaces, and Nano-agents for analysis inside cells are expected in short term (before 2010).

Theranostic nanomachines - ~2025

Conclusions (cont.)

Most important action to foster realization - **increase in basic/applied research** (with different degrees among the statements).

Fiscal/financial measures - least needed action.

Regulation activity is needed (according to >40% of respondents) for **Protein & DNA chips** and **Targeted drug delivery**. For all other statements less than 40% of the respondents recommend regulation activities.

Solution of ethical problems and public acceptance issues is needed to enhance the realisation of several statements, especially:

in vitro construction of human organs, theranostic nanomachines and **self-repairing in artificial systems.**

WHAT NEXT?

Towards a strategic plan of N2L

Possible next activities:

- **Stimulate discussions** among N2L members on the results, to better shape the conclusions and provide inputs to N2L policy and programmes.
- **Brainstormings** with relevant specialists – Prospective Workshops
- **Second round** - especially on: ***topics with low consensus***
  missing topics
- **Benchmarking** of relevant foresight studies worldwide

Key issues for discussions: detail barriers, resolving controversies…

Examples of topics worth discussion:

- ***Lab on chip:*** highest impact & prospects ***but*** disagreement on barriers.
- ***Living self-repairing abilities implemented in artificial systems:***

high disagreement on time of realization, high percentage of “never”, “many barriers” and “need to solve ethics/public acceptance problems”.

Extra slides follow

Survey structure

Statement9: Biological energy conversion systems (e.g. biomolecular motors) are practically used in artificial micro and nano systems.

A- Your level of expertise on this statement

- ○ Expert
- ○ Knowledgeable
- ○ Familiar
- ○ Unfamiliar

B- When will the statement occur ?

- ○ Before 2010
- ○ 2011 – 2015
- ○ 2016 – 2020
- ○ After 2020
- ○ Never

C- What will be the level of impact of this achievement on the following domains:

(Please mark the appropriate box for each domain)

Science and Technology	○ Very high	○ High	○ Low	○ Negative
Environment	○ Very high	○ High	○ Low	○ Negative
Quality of Life	○ Very high	○ High	○ Low	○ Negative
The labor market	○ Very high	○ High	○ Low	○ Negative

D- What are the prospects of commercialization of this technology in the following areas:

(Please mark the appropriate box for each domain)

Medicine and Health	○ Very High	○ High	○ Low	○ Impossible
Security	○ Very High	○ High	○ Low	○ Impossible
Environment	○ Very High	○ High	○ Low	○ Impossible
Agriculture and Food	○ Very High	○ High	○ Low	○ Impossible
Consumer Products	○ Very High	○ High	○ Low	○ Impossible
Other (please specify) :				
	○ Very High	○ High	○ Low	○ Impossible

E- What limits the prospects of commercialization:

(Please make the appropriate selection for each domain)

Medicine and Health: ------>

- ------>
- Many barriers
- No needs
- Needs Already fulfilled by other technologies
- Nothing limits

Security

Environment

Agriculture and Food: ------>

Consumer products: ------>

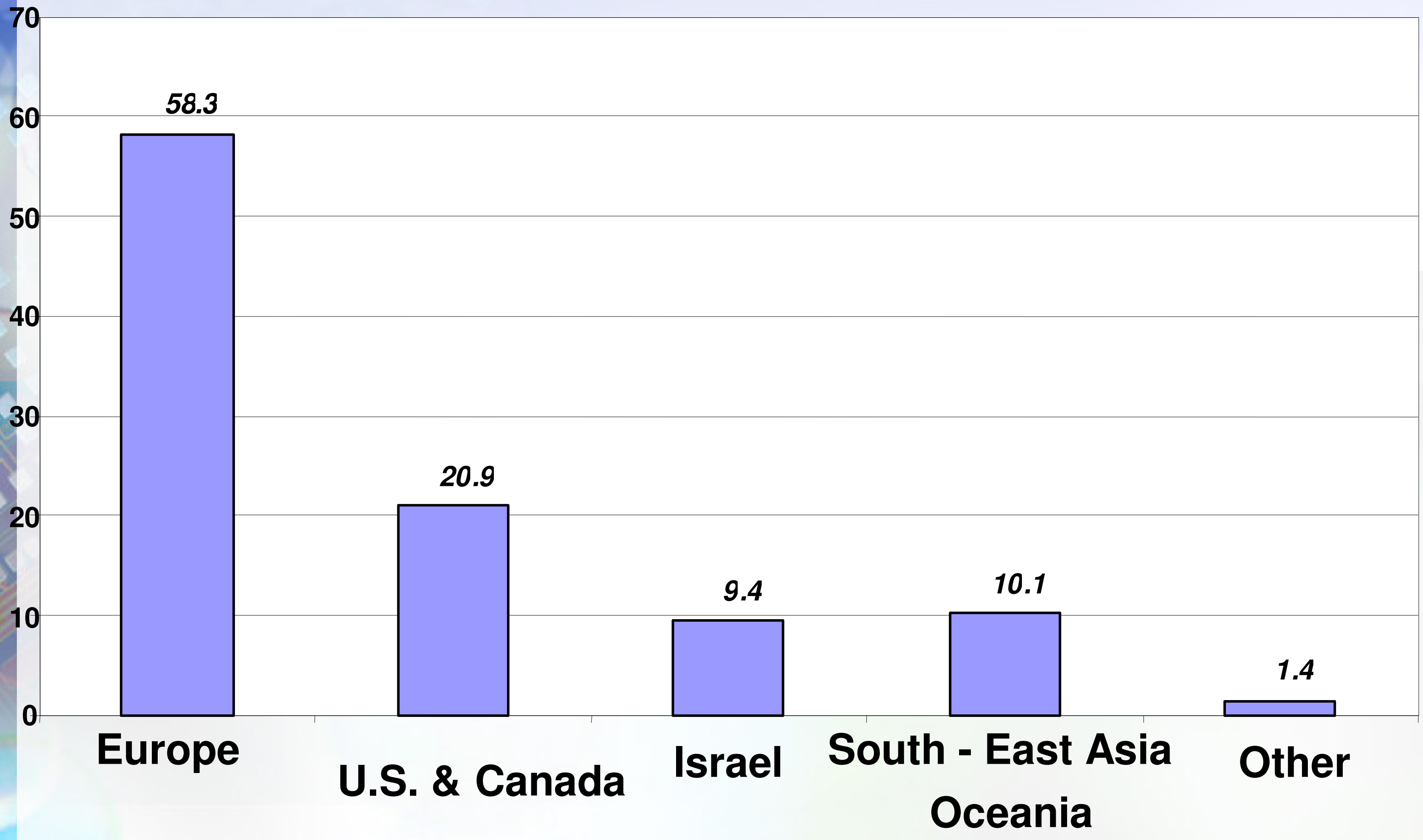
F- Actions needed to enhance the likelihood of the statement

(you can tick more than one : hold the ctrl-key while clicking)

- Increase in basic research
- Increase in applied R&D
- Fiscal and financial measures
- Regulations (e.g. standards)
- Solve ethical problems
- Public acceptance

G- Please submit comments you might have regarding this statement :

Respondents countries (%)

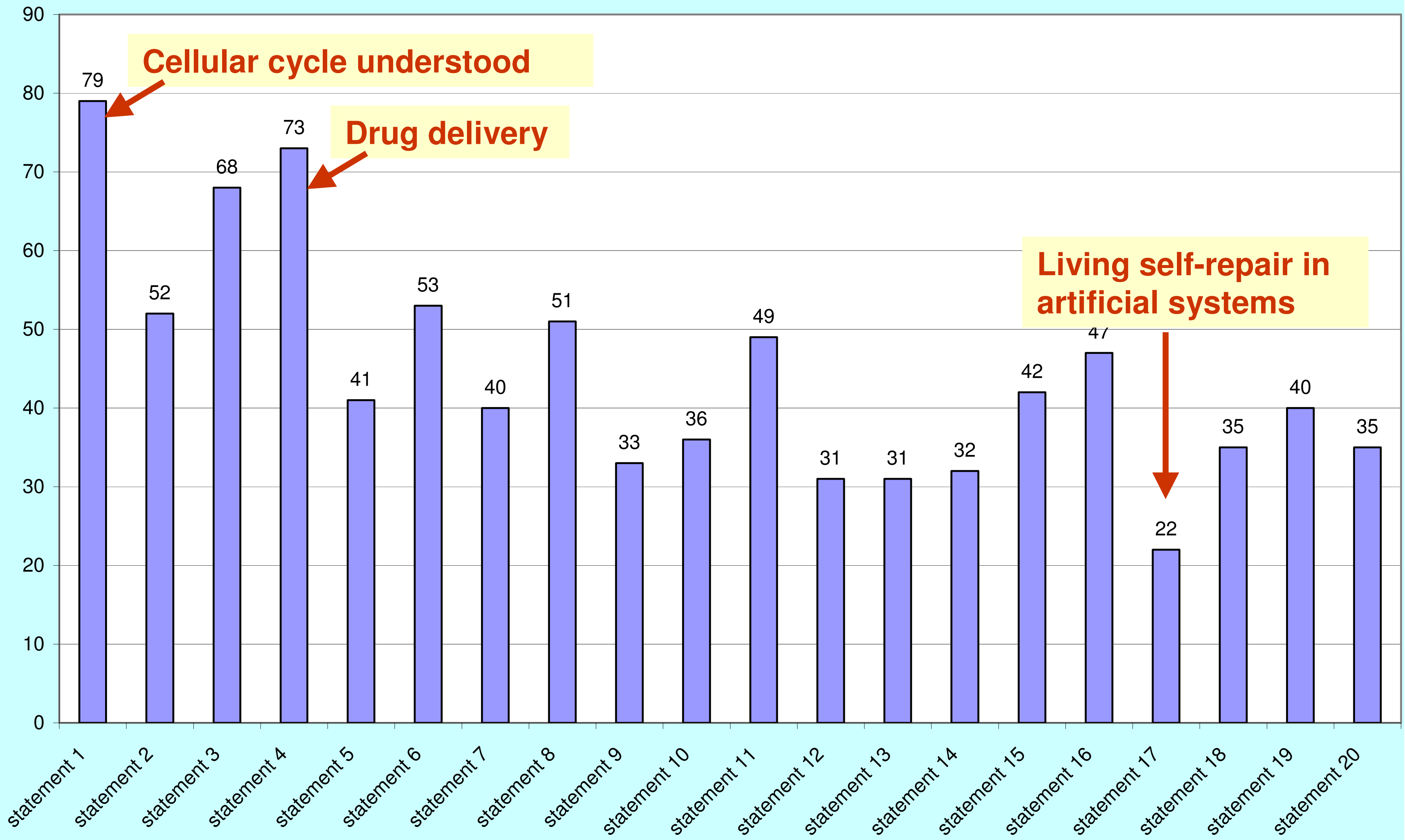


COUNTRY

	Frequency	Percent
1 U.S.A	27	19.4
2 Israel	13	9.4
3 U.K	6	4.3
4 Germany	18	12.9
5 France	13	9.4
6 Italy	6	4.3
7 Austria	3	2.2
8 Romania	5	3.6
9 Switzerland	7	5.0
10 Sweden	3	2.2
11 Spain	5	3.6
12 Irland	3	2.2
13 Greece	4	2.9
14 Finland	1	.7
15 Denmark	1	.7
16 Norway	1	.7
17 Netherland	2	1.4
18 Lithvania	1	.7
19 Belgium	1	.7
20 Bulgaria	1	.7
21 Canada	2	1.4
22 Australia	4	2.9
23 New Zealand	1	.7
24 Japan	2	1.4
25 China	3	2.2
26 Singapure	2	1.4
27 India	1	.7
28 South Korea	1	.7
29 Nigeria	1	.7
30 Brazil	1	.7
Total	139	100.0

Number of respondents	No. of statements answered
35	1
47	2-5
26	8-10
14	11-15
17	16-20
Total= 139	

Number of answers per statement



statement	N	Expert	Knowledgeable	Familiar
1	79	12.7% (10)	45.6% (36)	41.8% (33)
2	52	3.8% (2)	46.2% (24)	50% (26)
3	68	25% (17)	47.1% (32)	27.9% (19)
4	73	16.4% (12)	50.7% (37)	32.9% (24)
5	41	22% (9)	31.7% (13)	46.3% (19)
6	53	20.8% (11)	52.8% (28)	26.4% (14)
7	40	20% (8)	30% (12)	50% (20)
8	51	19.6% (10)	39.2% (20)	41.2% (21)
9	33	15.2% (5)	39.4% (13)	45.5% (15)
10	36	22.2% (8)	33.3% (12)	44.4% (16)
11	49	22.4% (18)	40.8% (20)	36.7% (18)
12	31	35.5% (11)	45.2% (14)	19.4% (6)
13	31	35.5% (11)	35.5% (11)	29% (9)
14	32	18.8% (6)	43.8% (14)	37.5% (12)
15	42	26.2% (11)	47.6% (20)	26.2% (11)
16	47	36.2% (17)	44.7% (21)	19.1% (9)
17	22	18.2% (4)	27.3% (6)	54.5% (12)
18	35	25.7% (9)	28.6% (10)	45.7% (16)
19	40	22.5% (9)	30% (12)	47.5% (19)
20	35	20% (7)	34.3% (12)	45.7% (16)

Limits to commercialization - Environment (%)

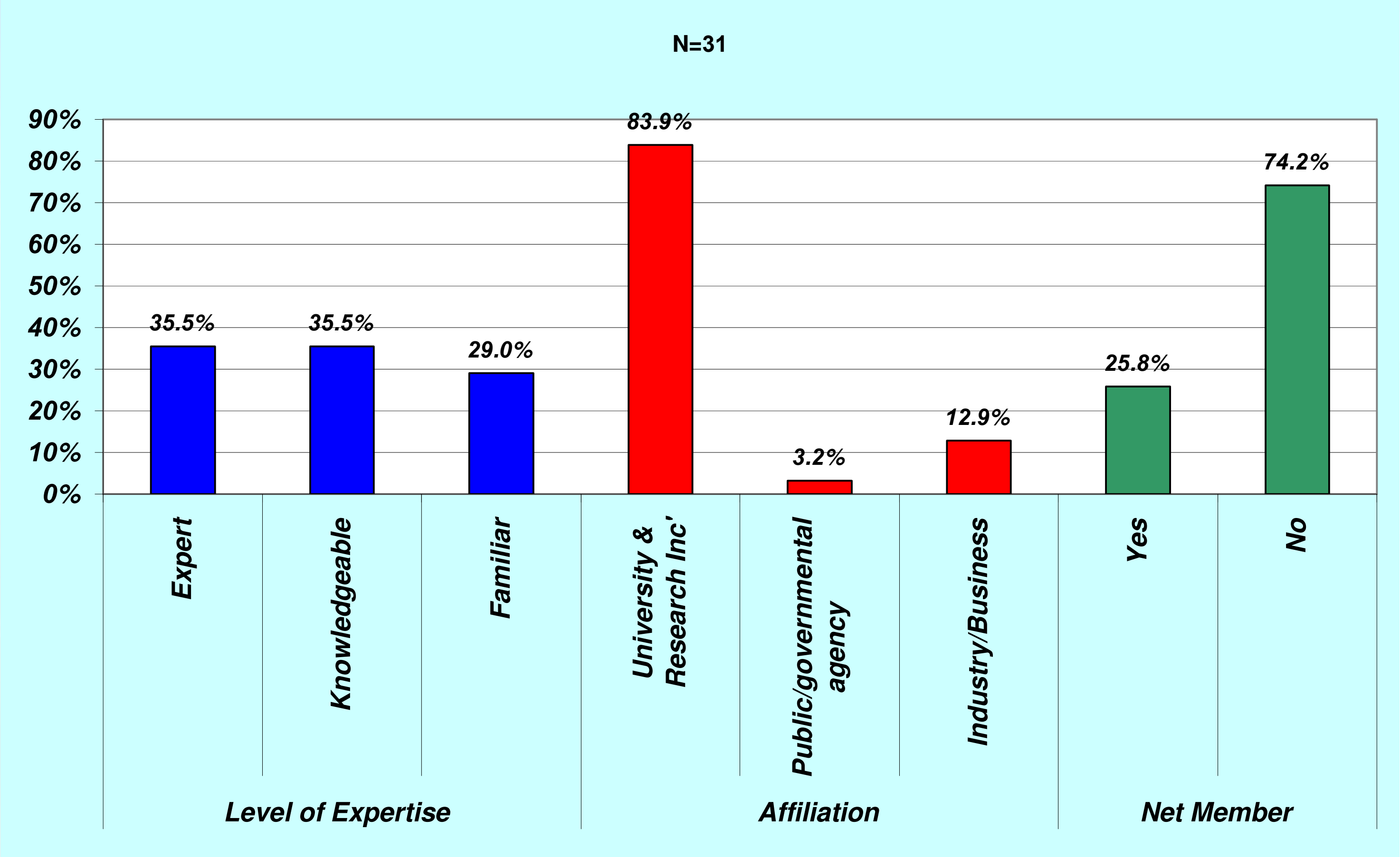
(large levels of disagreement highlighted)

tatement	Nothing limits	Many barriers	Needs already fulfilled	No needs
cellular cycle	34.5	32.8	19.0	13.8
in vitro construction of human organs.	8.6	11.4	5.7	74.3
nanostructured biomaterials.	40.4	25.5	19.1	14.9
Targeted drug delivery	16.3	26.5	6.1	51.0
Smart probes used in in-vivo.	30.0	26.7	13.3	30.0
Biodetection with smart nano-surfaces	57.9	23.7	7.9	10.5
Nanotools for manipulation inside cells	16.0	32.0	4.0	48.0
Nano-agents for analysis inside cells	34.4	21.9	9.4	34.4
Bio energy conversion in micro/nano systems	22.7	45.5	18.2	13.6
). Bio-inspired materials	44.4	25.9	14.8	14.8
l. Labs on chip	45.7	28.6	5.7	20.0
2. Protein & DNA chips integrated	35.3	17.6	11.8	35.3
3. Protein chips for personal use.	26.3	26.3	15.8	31.6
4. cells on chips replace animal testing	40.0	40.0	40.0	20.0
5. Biosensors for single molecules	31.0	41.4	17.2	10.3
5. Self-assembly widely implemented	36.1	47.2	8.3	8.3
7. Self-repairing in artificial systems.	28.6	42.9	14.3	14.3
3. Nanomachines inside the body.	5.0	40.0	0	55.0
). Chips employing biomolecules	47.8	30.4	13.0	8.7
). Chips made by using DNA / peptides	10.0	30.0	40.0	20.0

Actions needed to foster realization

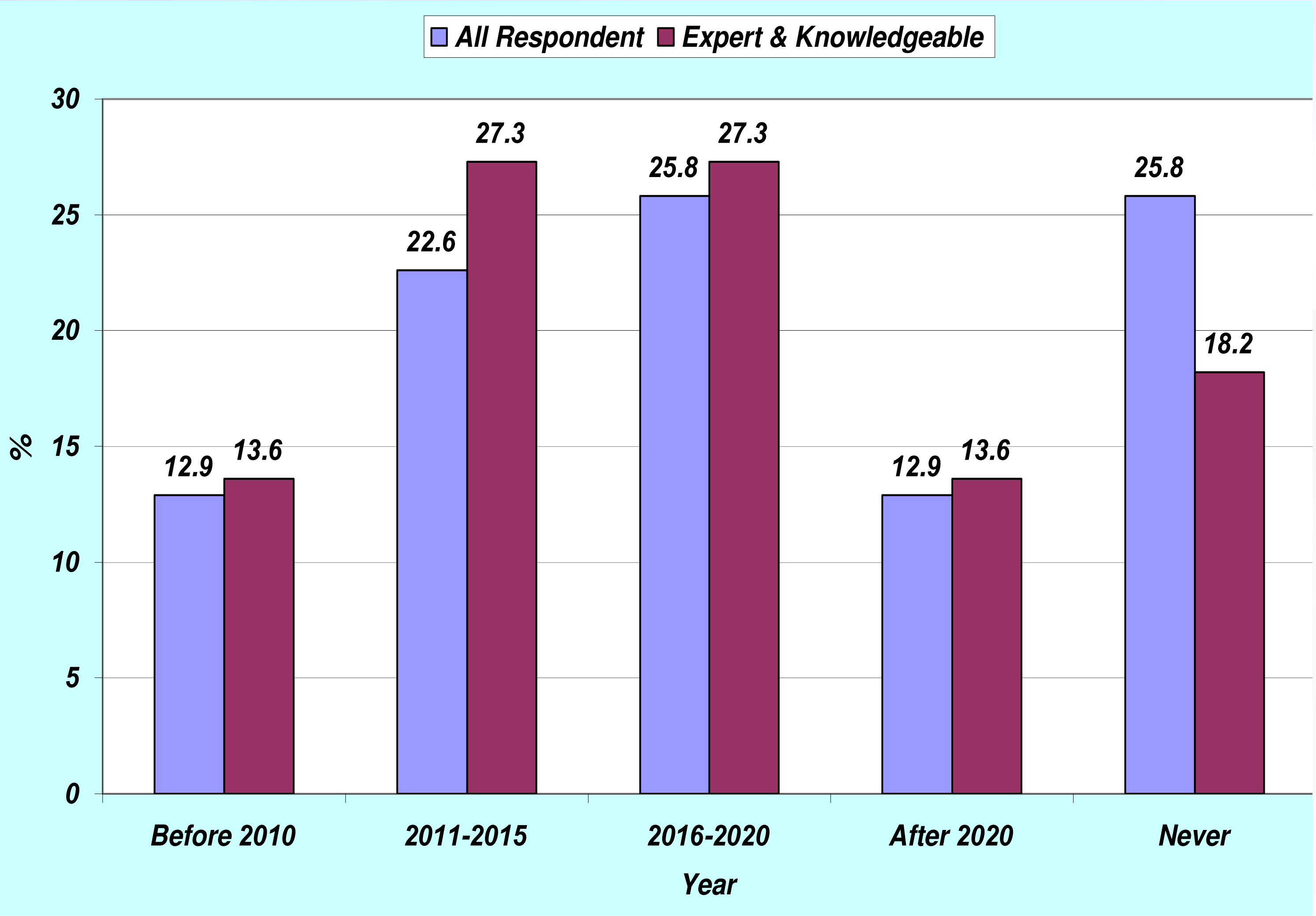
statement	N	Increase in basic/applied research	financial measures	Regulation	Solve ethical problems or public acceptance
cellular cycle	78	79.5	17.9	20.5	38.5
in vitro construction of human organs.	50	78.0	22.0	36.0	**62.0**
nanostructured biomaterials.	65	81.5	26.2	32.3	24.6
Targeted drug delivery	73	82.2	24.7	39.7	39.7
Smart probes used in in-vivo.	40	**90.0**	22.5	37.5	32.5
Biodetection with smart nano-surfaces	53	88.7	15.1	20.8	11.3
Nanotools for manipulation inside cells	38	86.8	15.8	7.9	28.9
Nano-agents for analysis inside cells	51	84.3	17.6	19.6	37.3
Bio energy conversion in micro/nano ystems	32	84.4	25.0	15.6	28.1
). Bio-inspired materials	36	**88.9**	19.4	25.0	22.2
l. Labs on chip	49	87.8	24.5	36.7	28.6
2. Protein & DNA chips integrated	31	80.6	25.8	48.4	35.5
3. Protein chips for personal use.	31	64.5	19.4	22.6	32.3
4. cells on chips replace animal testing	32	68.8	18.8	37.5	37.5
5. Biosensors for single molecules	42	88.1	28.6	26.2	16.7
5. Self-assembly widely implemented	46	**91.3**	19.6	15.2	17.4
7. Self-repairing in artificial systems.	20	85.0	15.0	25.0	**50.0**
3. Nanomachines inside the body.	35	85.7	25.7	22.9	**57.1**
). Chips employing biomolecules	40	75.0	15.0	22.5	20.0
). Chips made by using DNA / peptides	35	82.9	25.7	8.6	17.1

Example of detailed results
13. Protein chips are widely used for personal use

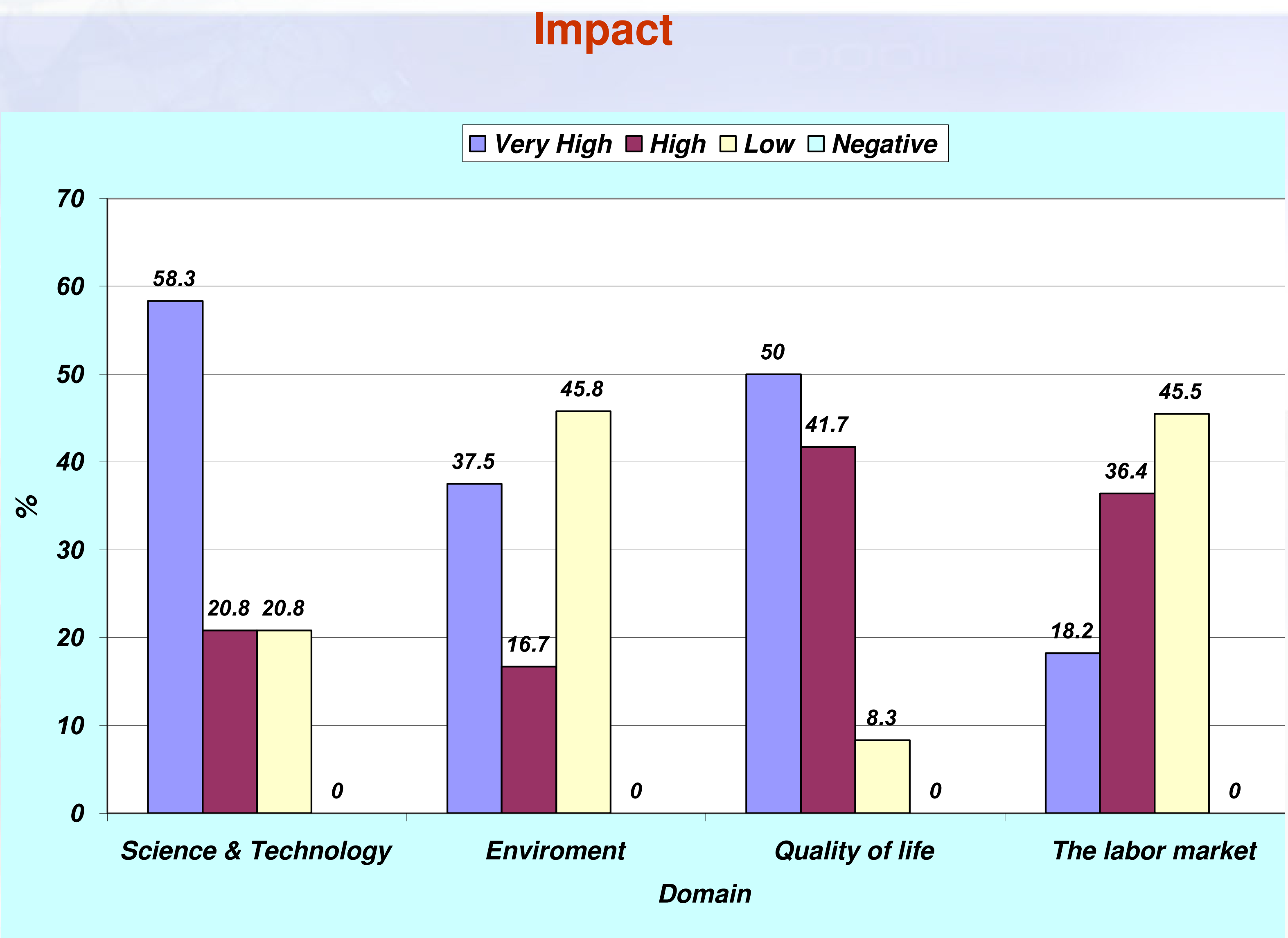


13. Protein chips are widely used for personal use

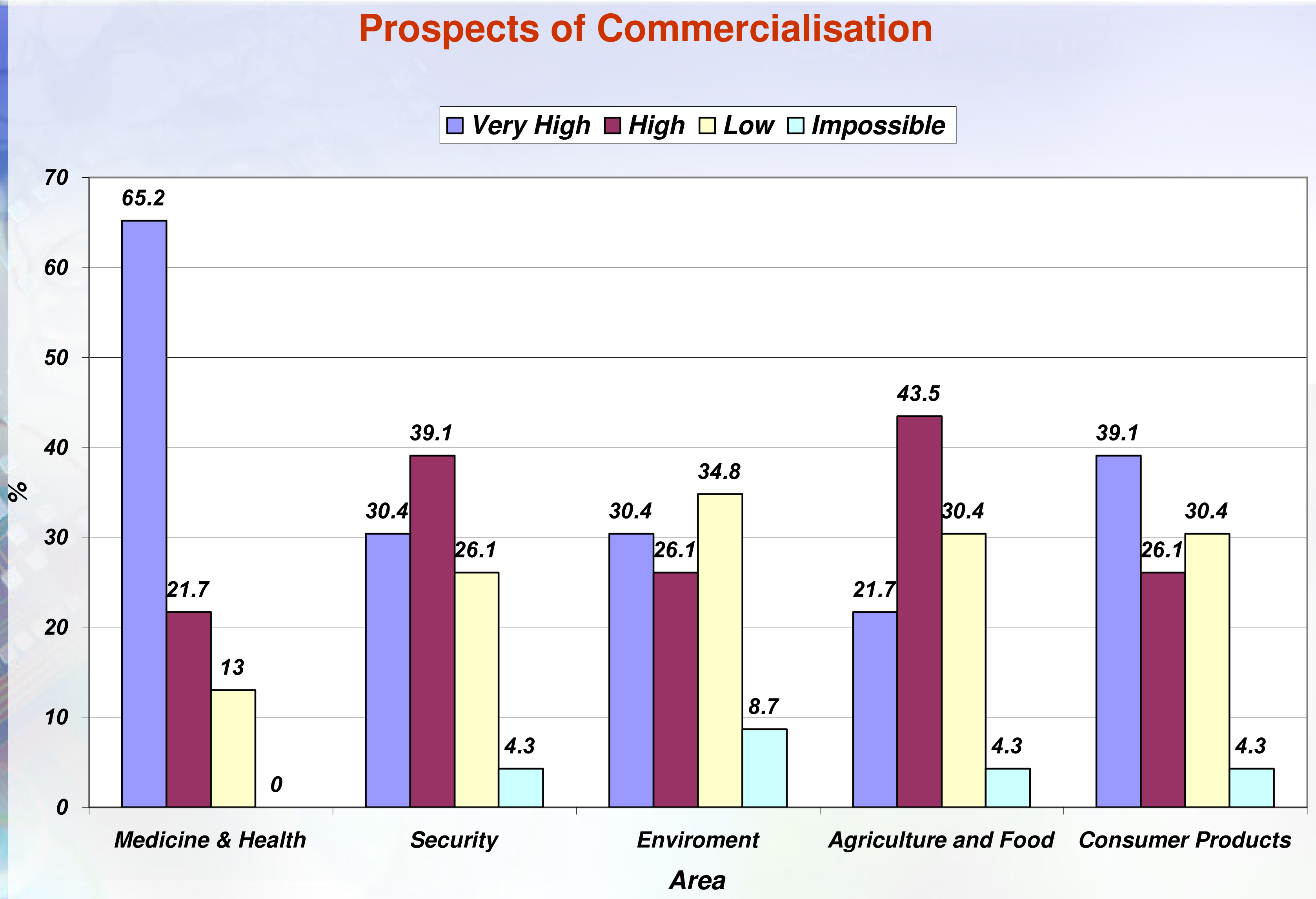
Year of realisation



13. Protein chips are widely used for personal use

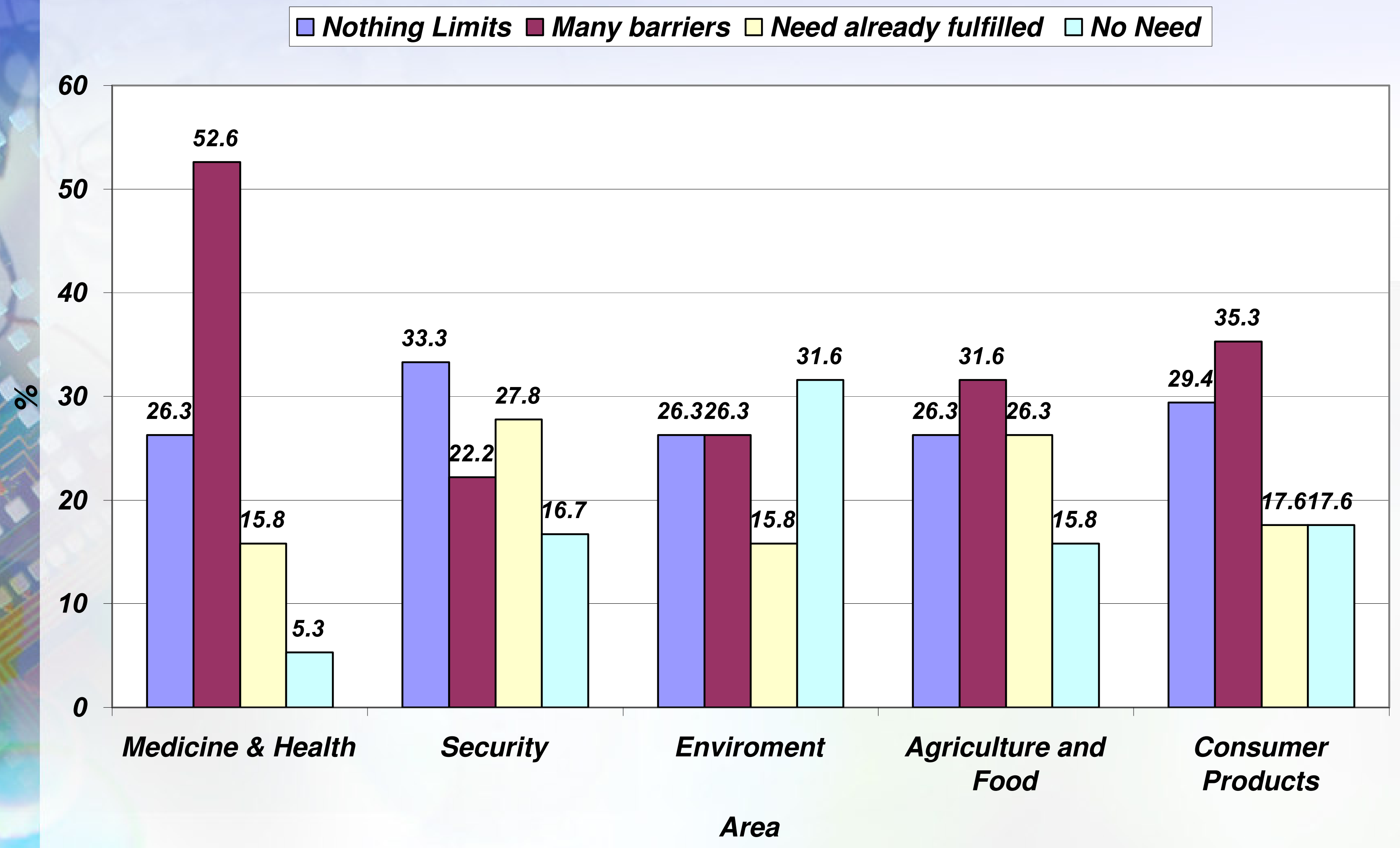


13. Protein chips are widely used for personal use



13. Protein chips are widely used for personal use

What limits the prospects of commercialisation?



13. Protein chips are widely used for personal use

Needed Actions

	All Respondents N=31	Experts and Knowledgeable N=22
	%	%
Increase in basic research	48.4	54.5
Increase in applied R&D	58.1	63.6
Fiscal and financial measures	19.4	18.2
Regulations (e.g standards)	22.	27.3
Solve ethical problems	22.6	27.3
Public acceptance	32.6	36.4